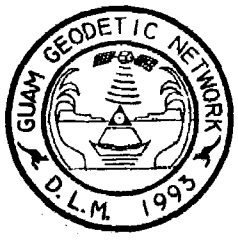
1993 GUAM GEODETIC NETWORK PROJECT

FINAL REPORT

Department of Land Management

Government of Guam



Prepared by:

South Australian Department of Environment and Natural Resources

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November 1995

Prepared by:

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EXECUTIVE SUMMARY

The 1993 Guam Geodetic Network Project (1993 GGN) was implemented between April 1994 and August 1995. As the Department of Land Management's (DLM) consultant, the South Australian Department of Environment and Natural Resources was responsible for management and implementation of the project utilising DLM personnel.

The main objectives of the project were to assist DLM to upgrade the 1963 Guam Geodetic Triangulation Network to a modern, accurate and readily accessible geodetic network, and to provide technology transfer to DLM staff regarding the application of Global Positioning System (GPS) technology to surveying.

Some 2200 new survey marks have been established island wide as part of the new geodetic network of some 2630 survey marks. The positions of all points have been determined very precisely using state of the art GPS survey technology to provide a world standard geodetic network. These marks are readily accessible to all survey practitioners who will be required to connect all surveys to the new network.

In addition to providing the new network, the project has provided the necessary supporting infrastructure to ensure long term sustainability of the technology transfer and preservation of the network marks. The project developed the Guam Survey Mark System, a Mark Maintenance Program and amendments to both survey legislation and the survey manual.

The Guam Survey Mark System provides a repository for the manual and computerised data generated by the project. Coordinates and related information are stored in the data base. This information will be available to both government and private surveyors and other interested parties.

To ensure long term protection of the survey marks, a Mark Maintenance Program was developed. All organisations and individuals are required to obtain clearance from the Territorial Surveyor before commencing construction and excavation work within public easements along highways and roads. The program also provides for extension of the network into areas of new development to maintain a suitable density of marks.

The Legislation Study provided amendments to existing surveying legislation to allow for introduction of the network, a guide for surveyors and suggestions for improving Guam's cadastre. Among other things, the amendments that became Public Law 23-31 establish legal authority for the 1993 GGN, require surveyors to connect to the new network and increase the penalty for disturbing survey marks to $5000.

During the project, senior GovGuam officials visited South Australia on a Management/Study Tour to examine the state's approach to survey, land administration, mapping and LIS, and innovations in those areas. Two of the DLM personnel assigned to the project will undertake a further three months of training in South Australia, commencing in January 1996.

To ensure that Guam gains the maximum benefit from the project there must be an ongoing commitment to the goals of the project and proper utilisation of the network. Support must be provided for maintenance and extension of the network. DLM must build on the

foundation that the 1993 GGN has provided and initiate some of the proposals for improving the cadastre including a general improvement in survey practices.

Utilisation of the 1993 GGN will ensure that surveys are properly controlled and will prevent the proliferation of gaps and overlaps. However it does not provide an instant answer to Guam's existing problems which can only be resolved by resurveying the confused boundary areas.

It is suggested that serious consideration be given to the following recommendations:

That DLM staff should acquire a thorough understanding of map projections, geodetic datums and transformations and consider engaging a consultant to supervise the transformation process.

That DLM consider developing local grid transformation parameters to enable the transformation of all data to the 1993 geodetic datum.

That DLM give serious consideration to relevelling the vertical network to determine the extent of degradation due to geophysical activity and to define a new vertical datum for Guam.

That DLM create the position of Mark Maintenance Officer within the Geodetic Section and appoint a suitable person to the position.

That DLM revise the "Save That Survey Mark" brochure, print another batch of brochures and make them readily available to the utility agencies, contractors and the public.

That DLM formally create the Geodetic Section within Survey Division and that it be allocated the necessary resources in the form of personnel, office space, furniture, equipment, vehicles and ongoing funding to enable it to carry out its functions and maintain and replace equipment as necessary.

That the Territorial Surveyor takes the strongest action possible to enforce the provisions of Public Law 23-31 related to protection of marks to demonstrate that DLM is serious about the preservation of the network and publicises his actions in this regard.

That DLM reviews the Mark Maintenance Program at the end of the initial inspection of marks.

That DLM engage the assistance of a suitably qualified consultant, in modern survey techniques and practices, to coordinate the total revision of Guam's Survey Law, Survey Regulations and the Survey Manual.

That DLM engage the assistance of a suitably qualified consultant, to coordinate a Pilot Study within a Confused Boundary Area from which the appropriate survey and legal procedures will be developed for the resolution of all such boundary problems throughout Guam.

That DLM introduce fees for the examination of survey maps.

That DLM review the structure, role and resources of Survey Division to ensure that it is adequately equipped to carry out its existing tasks, meet the obligations placed upon it by the 1993 GGN and to gradually improve Guam's cadastre to meet the community's expectations and demands.

It is recommended that DLM give consideration to appointing at least one and preferably two professionally qualified surveyors. Ideally they should be drawn from overseas where they have had extensive exposure to a variety of modern techniques so that they can guide DLM and the private sector in the development of modern and appropriate procedures.

That DLM give consideration to extending the training of their two key GPS personnel to full bachelors degree level.

That DLM actively encourage the involvement of Guam's surveying community with fellow professionals throughout the region.

That DLM and the surveying profession consider the possibilities of promoting a cooperative relationship between the University of Guam and a suitable off-island university to improve the survey education available on Guam for both those interested in entering the surveying profession and those wishing to extend their existing surveying education.

It is recommended that DLM and GovGuam re-examine the LIM Strategy to ensure a planned, logical, fully integrated approach to the management and integration of the various land related data sets.

The project has demonstrated how advanced satellite technology can be applied to the development of an accurate geodetic network, effectively achieving in less than eighteen months a task that would otherwise have taken many years to complete.

Development, resource management and land administration relate to land tenure and all depend upon accurate surveying and mapping. The 1993 GGN is an accurate homogeneous control network providing the basic reference framework for all surveying, mapping and land related information in the territory. This spatial framework provides the basis for the integration of the different elements of a successful Land Information System.

1.1 Background

Ordered social and economic development relies upon a sound land administration system. Without the security of tenure and boundaries, that result from a sound land administration system, citizens and developers are reluctant to invest in appropriate development. The Government of Guam and in particular the Department of Land Management has recognised the need for such a system and embarked on a number of programs to achieve this goal.

In 1991 the Territorial Planning Council engaged the South Australian Government to assist with the preparation of a strategic plan for the management of Guam's land information. This study produced a comprehensive document entitled the *Land Information Management Strategy* which identified a number of areas in which improvements were recommended. Some particular areas of concern related to the quality of the basic cadastre, which is the record of legal rights relating to land parcels and the record of the spatial extent of those parcels.

A sound geodetic network provides the ability to spatially locate the cadastre and all land information and is required to support a modern land information system. The study drew attention to the serious shortcomings of the existing 1963 Guam Geodetic Triangulation Network of which it was estimated perhaps 75% was missing and the absence of any network in areas of development subsequent to 1963. The state of the network has had a serious effect on the quality of cadastral surveys with resultant gaps and overlaps. Accordingly it was recommended that a modern, accurate and complete geodetic network should be established as a matter of urgency. The report supported the desire of the then Director, DLM, to upgrade the existing geodetic network to provide the spatial framework for the Territory's cadastre and land information needs.

Aware of the limited resources of DLM's Survey Division, the lack of expertise in geodetic surveying both within DLM and the private sector, and recent developments in satellite surveying, the then Director sought government to government assistance from agencies with the necessary expertise to undertake the establishment of a modern geodetic network. He communicated with two US Federal agencies, the National Geodetic Survey (NGS) and Bureau of Land Management (BLM), and the South Australian Department of Environment and Natural Resources (DENR). After numerous communications and meetings both in Guam and on the mainland and the preparation of proposal documents, the former Director decided to accept the DENR proposal. The decision was based on a comparison of the financial aspects, project management proposals, proposed training and technology transfer and other considerations.

Accordingly the Government of South Australia was appointed as the Administrative and Technical Consultant for the 1993 Guam Geodetic Network Project. The project was under the administration of the Territorial Surveyor. DENR provided consultants throughout the project to ensure an effective technology transfer to DLM. The philosophy behind the South Australian proposal for the project was based upon both the long term and short term placement of consultants on-island for the duration of the project. Under this approach the responsibility for the successful implementation of the project rested with DENR. They undertook all aspects of project management to ensure effective training and technology transfer.

1.2 Objectives

The objectives of the project were to assist DLM to:

- Upgrade the Guam Geodetic Triangulation Network to a modern, accurate, and readily accessible geodetic network;
- Provide technology transfer to DLM staff regarding the application of GPS technology to surveying;
- Develop and implement a Survey Mark System into which data generated by the project will be incorporated;
- Develop a Mark Maintenance Program to ensure that the new marks are not allowed to be destroyed over time and the network deteriorate;
- Develop amendments to legislation and provide the surveying industry with a guide as to how new legislative requirements will affect it.

The requirements of an effective network are:

- appropriate accuracy of coordinates;
- well maintained survey marks;
- sufficient density of marks to enable all surveys to be adequately connected;
- an increase in density of marks as development occurs;
- an adequate record system holding information related to marks.

The 1993 Guam Geodetic Network Project has met all the above requirements. It has provided a Primary Network of very high accuracy comprising twenty eight (28) survey marks evenly distributed over the island. More importantly it has established Secondary and Tertiary Networks of some 2630 survey marks that will be readily accessible to all survey practitioners using conventional survey techniques.

1.3 Method of Survey

The 1993 Guam Geodetic Network (1993 GGN) was established using Global Positioning System (GPS) satellite technology. Primary, secondary and tertiary stations were coordinated using a combination of static and kinematic GPS techniques.

1.4 Project Implementation

The project was divided into two distinct phases. Phase I consisted of analytical and preparatory work. Phase II was concerned with implementation of the project, that is the physical establishment of the network and implementation of the other supporting components.

1.4.1 Phase I

Phase I of the project was undertaken during July and August 1993. Phase I was essentially a three week study on Guam to define the parameters for implementation of Phase II. The

study involved intensive consultation with key Government of Guam personnel, and in particular, those of the Department of Land Management (DLM). Consultations were also held with surveyors from the private sector.

A brief summary of Phase I is provided in Section 2.

1.4.2 Phase II

Implementation of Phase II, which was scheduled to take about eighteen months, commenced on 11th April 1994. The project was implemented in accordance with the Project Work Plan which forms Appendix 1 of the *Scope of Work*. The final on island stage of the project was completed on 18th August 1995 as scheduled. This was followed by the final adjustment of the data and preparation of the *Final Report* in Australia. Data will be returned to Guam with the *Final Report* for input into the computer data base by DLM personnel. The project also provides for some additional training to take place in Australia in early 1996.

This report concentrates on the implementation of Phase II.

2.1 Introduction

Phase I of the project was a three week study on Guam to define the parameters for implementation of Phase II. It was undertaken during July and August 1993. During the study there were intensive consultations with key Government of Guam personnel, and in particular, those of the Department of Land Management (DLM), and also with surveyors from the private sector.

2.2 Objectives

The objectives of Phase 1 were to conduct four studies, being:

- The Preliminary Study,
- The Transformation Requirements Study,
- The Broad Systems Design for a Mark Register,
- The Development of Guidelines for Collection of Data.

2.3 Consultants

The work was undertaken by a team of technical advisers from DENR, comprising:

- Andrew Dyson - Australian Team Leader,
- Andrew Jones - Geodesist,
- Craig Macauley - Survey Data Base Expert,
- David Borchardt - Tertiary Network Expert.

The team was accompanied by:

- Tony Bew - Project Director.

2.4 The Studies

2.4.1 The Preliminary Study

All aspects of the geodetic network and project implementation were investigated. Such matters as the density of marks, the total number of marks, mark construction, witnessing and maintenance were considered. The viability of GPS kinematic observations in tropical atmospheric conditions was investigated.

It was recommended that the WGS 84 geodetic datum be adopted as the territorial datum for Guam, and that a local Transverse Mercator projection, to be referred to as the Guam Map Grid, be adopted for cadastre related applications in Guam.

2.4.2 Transformation Requirements Study

Investigations were carried out into transformation parameters for the geodetic datums and the map grids. Provisional values were determined from GPS field work carried out during the Preliminary Study. A preliminary geoid map was developed from these observations and an average separation value of 56 metres was determined.

2.4.3 Broad Systems Design for a Mark Register

To be known as the Guam Survey Mark System (GSMS), topics investigated included; the system components, design considerations, required and existing hardware and software, the system development plan, data file and mark location card creation, survey mark index creation, records maintenance, organisational and other issues for the future development of the GSMS.

2.4.4 Development of Guidelines for the Collection of Data

Various topics reported upon included; collection of digital cadastral data by DLM and other GovGuam agencies, the transformation of coordinates in existing COGO (coordinate geometry) files and planning layers, retention of source data, date stamping, accuracy codes and custodianship of cadastral data.

2.5 Reports

A comprehensive report entitled the *Phase I Final Report* was prepared. The report contained numerous recommendations to DLM for implementation of the project.

As a result of this report the *Phase II Scope of Work* was prepared. Phase II of the project was implemented in accordance with the *Scope of Work.*

3.1 Introduction

Phase II of the project was divided into a number of major components, as follows:

- PRIMARY NETWORK
- DEVELOPMENT OF THE GUAM SURVEY MARK SYSTEM
- DEVELOPMENT OF A MARK MAINTENANCE PROGRAM
- LEGISLATION STUDY
- SECONDARY & TERTIARY NETWORKS (PARTS I, II & III)
- FINAL ADJUSTMENT (& PREPARATION OF FINAL REPORT)
- TRAINING IN AUSTRALIA

All the on-island components of the project will be considered in this section. The Final Adjustment Component will be dealt with in Section 4. The final component, Training in Australia, is scheduled to commence in January 1996. The outputs expected from each component were detailed in the *Scope of Work* and will be summarised below.

3.2 Consultants

The following consultants were on island for either some or all of the project:

• Andrew Dyson	-	Australian Team Leader	-	(full term)
• David Borchardt	-	Tertiary Network Expert	-	(full term)
• Craig Macauley	-	Survey Data Base Expert	-	(short term)
• Peter Kentish	-	Survey Legislation Expert	-	(short term
• Chris Jordan	-	Mark Maintenance Expert	-	(short term)
• Tony Bew	-	Project Director	-	(short term)

In addition the following consultant was involved in the off-island Final Adjustment Component:

- Andrew Jones - Geodesist

3.3 Project Preparation

Prior to implementation, DENR undertook the necessary project preparation activities in Australia and Guam. This included:

- acquisition, delivery and testing of agreed GPS, ancillary and computing equipment on GovGuam's behalf;

- acquisition and delivery of agreed monumentation and witnessing materials on GovGuam's behalf;
- design of project field pages.

Except from some minor items, all equipment was on island as scheduled at commencement of the project. Difficulties encountered in opening accounts on Guam, and the problems associated with purchasing materials and supplies within the rigid confines of the GovGuam purchasing procedures wasted much time, caused considerable frustration and resulted in some delays.

DLM in return was required to provide all necessary support in terms of office accommodation, general office equipment, stationery supplies and transport for DENR consultants and DLM personnel.

Numerous delays were experienced in providing the project with the necessary equipment, supplies and vehicles in addition to the delay in availability of the project office space. Of particular concern were the delays in providing international phone and fax facilities and the near three month delay in providing a satisfactory photo copying machine. These delays added to the burden on the consultants to keep the project on schedule.

3.4 Primary Network

3.4.1 Expected Outputs

The Scope of Work stipulated the following outputs for this component of the project:

- design of Primary Network consisting of twenty five stations;
- construction of new Primary Network marks and reconstruction of any existing stations found to be sub-standard to the specifications in the *Scope of Work*;
- construction of reference marks for each primary mark, as appropriate, to the specifications in the *Scope of Work*;
- construction of datum monument to the specifications in the *Scope of Work*;
- preparation of station summaries for all primary marks;
- a minimum of three GovGuam personnel and one person from the Commonwealth of the Northern Marianas' (CNMI) Department of Natural Resources will have received one week of training in static GPS techniques, and further on-the-job training in static GPS observation techniques and field reconnaissance;
- two GovGuam personnel will have received basic training in reduction and processing of static GPS observations;
- observation of primary network to comply with US NGS specifications for either Order B or Order 1 (1 and 10 parts per million - 95% confidence level);
- a minimally constrained adjustment of the Primary Network.
- Network Diagram produced for the Primary Network.

3.4.2 Implementation

This component of the project has been completed and all of the expected outputs have been achieved and either meet or exceed the requirements.

The proposed design for the Primary Network, from the *Phase I Final Report,* was modified, after consideration of the GPS observations completed by both the NGS and Dr. John Beavan's Philippine Sea Plate Survey (PSPS) in 1993 and the proposed PSPS observations for 1994. Stations **PATI, NCS & IPACHOL** were deleted and stations **BIHU, GUMO, ROSA, ARP GUM, LOOK** and **DANDAN** were added to the design giving a total of 28 primary stations.

All primary marks including the datum monument and reference marks have been constructed in accordance with specifications. Station summaries have been prepared for all primary stations.

During this component the project cooperated extensively with Dr. Beavan who was on island to coordinate observations for his 1994 PSPS. This included placing project personnel, vehicles and equipment at his disposal. This was done to support Dr. Beavan, as requested by Mr. Frank Castro, former Director DLM, and to enable maximum benefit to be obtained from the PSPS for the 1993 GGN. The proposed work schedule was modified to ensure that the station marks were constructed before the PSPS observations commenced. Training and observations were undertaken in conjunction with Dr. Beavan's project whenever possible.

DLM staff received training in static GPS techniques and basic training in the processing of static GPS data as scheduled. There was no participation by personnel from CNMI, possibly due to their involvement with the PSPS campaign in the CNMI.

GPS observations were completed to the required specifications as confirmed by a minimally constrained adjustment of the Primary Network. A Network Diagram was produced utilising DLM's GIS and preliminary coordinates from the adjustment. A copy is included as Appendix 1.

3.4.3 Variations

The main variations from the expected outputs were as follows:

- an increase from 25 to 28 primary stations;
- five DLM personnel received training in static GPS techniques, but there was no involvement by CNMI personnel;
- adjustment of the data indicated that all observations exceeded the specifications as detailed in the *Scope of Work*, with relative accuracies for each pair of primary stations meeting the requirements for Order B.

3.5 Development of the Guam Survey Mark System

3.5.1 Expected Outputs

The Scope of Work stipulated the following outputs would be achieved from this component of the project:

- manual and computerised data generated by the 1993 GGN will be:
  - stored in the Guam Survey Mark System (GSMS), as the data becomes available;
  - readily accessible to private surveyors, GovGuam agencies, and the general public;
- DLM staff will be trained in the use and maintenance of the GSMS;
- user and system manuals will be prepared;
- a final report on the system will be prepared;
- upon completion of the project, final coordinates can be loaded into the register for storage.

3.5.2 Development & Implementation

This component of the project has been completed and all of the expected outputs have been achieved.

The development and initial implementation of the Guam Survey Mark System (GSMS) was undertaken over thirteen weeks from 25th April to 22nd July 1994. The coordinator of the component was Mr Craig Macauley, Survey Data Base Expert (SDBE). He received assistance from GovGuam staff in DLM and Data Processing Division (DPD), Department of Administration.

The primary objective of this component was to provide a repository for the manual and computerised data that is generated by the 1993 GGN Project. This objective has been achieved with the preliminary implementation of the three components of the GSMS:

- The Survey Mark Data Base (SMDB) is a computer based information system that stores coordinates and related information about the 1993 GGN marks;
- The Survey Mark Index will be a series of computer generated maps showing the position of each of the marks in relation to the cadastre;
- The Survey Mark Location Cards show the location of each mark in relation to surrounding features.

Provisional coordinates for all marks were loaded into the SMDB as they came available during the project. A Network Diagram has been produced which shows the Primary Network marks in relation to major routes and municipality boundaries. Survey Mark Location Cards have been produced for each survey mark in the Network.

The development of the GSMS took place in four phases:

- Detailed System Design;
- Development;
- Testing;
- Implementation.

The Detailed System Design Phase produced a report entitled *Guam Survey Mark System Detailed System Design* which formed the basis of the Development Phase. The Testing and Implementation Phases were based on a report entitled *Guam Survey Mark System Implementation Strategy*.

The *GSMS Implementation Strategy* contained an Implementation Plan which provided Survey Division and in particular, the Geodetic Section, with a guide for the introduction of the GSMS. A series of milestones were defined providing a detailed description of all tasks and responsibilities leading up to the final implementation of the GSMS at the end of the project. This information will then be available to the public via the GSMS Counter Service in Survey Division's Geodetic Section. The counter service had not been established at 18th August 1995.

It is emphasised that the role of the Geodetic Section is crucial to the success of the GSMS. Its personnel will be responsible to the Territorial Surveyor for maintenance of the GSMS and the integrity of the data.

The *GSMS Final Report* addressed some of the issues related to transformation of the existing data in DLM's GIS, from the existing projection/datum to the new projection/datum. Adoption of the new projection and datum in Public Law 23-31 requires DLM to transform all existing information in the GIS to the new systems. It pointed out that this transformation may not be a simple matter and suggested that DLM staff should acquire a thorough understanding of map projections, geodetic datums and transformations. The report also recommended that transformation of the recently acquired digital orthophoto data should be addressed by DLM if the data is to be utilised with the other data in the GIS.

3.5.3 Variations

The main variations from the expected outputs were as follows:

- in consultation with DLM and DPD it was agreed that the provision of a System Manual, if required, was the responsibility of DPD and it was inappropriate for the consultant to be involved in this matter. Accordingly the provision of a System Manual was omitted from the Project Brief with the consent of the Project Administrator;
- the *Implementation Strategy* specified that the Survey Mark Index maps would show the location of the GGN marks against the cadastral background plotted from the Adjusted Layer within the GIS. It was intended that index maps would be produced for each municipality. It was subsequently decided by the project team that it would be better to produce the index maps as an overlay for the ortho-photo maps. This will

provide a regular series of maps of a consistent size and the plotting requirements will be reduced considerably;

- the *GSMS User Manual* was revised by the Australian Team Leader and produced as a Quality Assurance Document (GGN/002) in the same format as the *Tertiary Network Manual* and *GPS Manual.*

3.6 Development of a Mark Maintenance Program

3.6.1 Objectives

The major objectives of this component of the project were to develop a Mark Maintenance Program to ensure:

- the safeguarding of survey marks placed on the project;
- the extension of the network into areas of new development as such development occurs.

This was to be achieved by a study involving the following:

- investigation of the need to establish a regular inspection program of all marks within the geodetic network;
- development of a comprehensive education program to educate agencies responsible for activities which would tend to destroy survey marks. Aspects to be covered will include both the value of the marks to Guam and the penalties associated with any damage caused;
- development of a general publicity program to make the public aware of the value and importance of survey marks;
- examining the feasibility of establishing an information service to advise utilities on the location of survey marks;
- developing procedures to protect network marks in danger of being destroyed by construction activities;
- developing procedures, in conjunction with the Legislation Study, to integrate new network marks into the geodetic network, in so doing assess whether:
  - the surveyor responsible for the subdivision carries out the survey to coordinate the network marks, or
  - DLM coordinate the marks at the completion of the subdivision, or
  - have the marks coordinated under contract;
- developing procedures for either GovGuam or private practice to suitably witness new marks placed;
- in conjunction with the Survey Data Base Expert, developing procedures for the Mark Reference data held in the Guam Survey Mark System to be updated;
- investigating the need to verify the status of marks shown as gone on survey plans;

- investigating the need for densification of the geodetic network in areas of anticipated development;
- indicating the necessary resources required by GovGuam to implement the Mark Maintenance Program (including personnel, training, surveying equipment and computer hardware and software requirements).

3.6.2 Program Development

The development of a Mark Maintenance Program was carried out between 25th April 1994 and 18th May 1994 by Mr. Chris Jordan, Mark Maintenance Expert, with the support of DLM staff and representatives of the various utility agencies. This component of the project has been completed and all of the expected outputs have been achieved.

The study established contacts with the utility agencies and detailed the measures to be implemented for an effective Mark Maintenance Program. Procedures were developed in conjunction with the Legislation Study for protection of the new survey marks placed for the 1993 GGN to prevent a recurrence of the destruction of the 1963 GGTN. The report suggested that a regular program of mark inspections should commence in 1996 and recommended that the operation of the Mark Maintenance Program should be reviewed after completion of the initial inspection.

The report also recommended the preparation of an illustrated brochure explaining what GGN survey marks are, the importance of their preservation, the need to obtain clearance from DLM before commencing construction work and the penalties for disturbing or destroying survey marks.

The program provides for the extension of the network into areas of new development to ensure a suitable density of marks, in relation to land use, is maintained throughout Guam. This component of the program entails a cooperative approach, as proposed in the *Legislation Study*, between the private sector and DLM. This approach will involve the private sector in placing and witnessing the new marks but the coordination will be done by DLM.

The report recommended the creation of the position of Mark Maintenance Officer (MMO) and listed the responsibilities of the position. It was intended that DLM would appoint an MMO who would take responsibility for the Mark Maintenance Program independent of the ongoing project activities. The MMO would also provide support to the project by taking responsibility for obtaining clearances from the utility agencies for the sites selected for the 1993 GGN marks and other duties related to establishing the new marks.

Full implementation of the program was dependent upon adoption of the proposed amendments to Guam's Survey Law contained in the Legislation Study.

3.6.3 Implementation

Because of the difficulties encountered in selecting a suitable member of the Survey Division to take on the responsibilities of the MMO, staff were allocated to be responsible for mark maintenance activities within the project. These activities were under the day to day control of the Guam Team Leader, Mr Tom Torres, and the general guidance of the consultants. In his report on the Management/Study Tour, the Territorial Surveyor recommended that DLM create the MMO position. Long term success of the Mark

Maintenance Program will depend upon creation of this position so that the MMO can give priority to maintenance activities. Requests for clearances must be dealt with quickly and action taken against anyone disturbing or destroying marks if credibility and the cooperation of agencies is to be maintained. This will only be achieved if the mark maintenance functions are formalised within the Geodetic Section and the MMO is able to allocate sufficient time to these functions.

In response to the recommendation in the Mark Maintenance Report, DLM produced a brochure, entitled *Save That Survey Mark.* Copies of the brochure were distributed to residents during reconnaissance and monumentation activities and to the utility agencies. By the end of the project, stocks were nearly exhausted and it was suggested that consideration be given to printing another batch of brochures as a matter of urgency. If a batch of a thousand succeeds in saving only one mark, it has probably paid for the brochures, if any more are saved it will be a direct saving to DLM.

Public Law 23-31, developed from the *Legislation Study*, provides for the protection of the new marks and gives the Territorial Surveyor the responsibility for maintaining them. This responsibility will rest with the Geodetic Section and to be successful sufficient resources must be permanently allocated to the section and the Mark Maintenance Program. The maintenance of the network will be ongoing and it must be given appropriate priority. Initial discussions with the utility agencies, whose work is most likely to destroy the marks, was encouraging, however experience during the project showed that most agencies and construction contractors had little regard for the network marks before the adoption of Public Law 23-31.

During the last week of the project all utility agencies were invited to a meeting concerning the protection of GGN marks and the requirement to seek clearance from the Territorial Surveyor before commencing any construction or excavation. Unfortunately the meeting was poorly attended and several agencies were not represented. It is critical to the eventual success of the project that all utility agencies are made fully aware of their responsibilities and obligations under Public Law 23-31, and the penalties that will be imposed for damaging or destroying GGN marks. It is imperative that contractors and agencies are made aware that DLM is serious about preventing the destruction of marks and will take the necessary action to recover the costs and penalties. Once an action is successful the message will quickly pass between the agencies and contractors. However if DLM fails to pursue those responsible for damage or destruction of marks the program will fail and the project's critics will be vindicated. Most of the 1963 GGTN marks have been lost and there is the very real danger of this being repeated unless DLM is able to make an ongoing and long term commitment to the Mark Maintenance Program by allocating sufficient resources, in the form of personnel, vehicles, equipment, materials and office space.

At conclusion of the project DLM had set up a Geodetic Section and made a commitment to provide the necessary resources. An amendment to the contract with DENR provided for the procurement of the necessary materials to enable extension and maintenance of the network.

As suggested in the report it would be appropriate to review the entire Mark Maintenance Program at the end of the initial inspection of the marks placed on the 1993 GGN Project. This review should assess if any alterations need to be made to ensure the program's continuing effectiveness and, if thought necessary, this review could be undertaken by DENR consultants.

3.7 Legislation Study

3.7.1 Objectives

The major objectives of this component of the project were to examine the following and prepare draft legislation, related to the geodetic network and the practice of surveying where required:

- the safeguarding of survey marks placed on the project;
- legal authority for the new network;
- legal implications of establishing the new vertical and horizontal datum, and map projection;
- existing legislation governing the penalties for disturbing or destroying survey marks and policing of the legislation;
- EDM calibration requirements;
- requirements that surveyors place marks suitable for inclusion in the control network as a part of normal surveying practice on new subdivision surveys;
- requirements to connect cadastral surveys to the control network;
- accuracy tolerances for connection to the network;
- adjustment of cadastral surveys to the network;
- density of new control marks to be placed as part of the subdivision process;
- opportunities for improving the cadastre.

As part of this study it was necessary to liaise and consult with members of the surveying profession, from both government and private sectors.

3.7.2 Implementation

The Legislation Study was carried out between 11th April 1994 and 5th May 1994 by Survey Legislation Expert, Mr Peter Kentish, Surveyor-General, DENR with assistance from staff of DLM.

To avoid a repetition of the destruction of the 1963 GGTN monuments, it was recommended that the penalties for damaging or destroying 1993 GGN marks should be increased from $500 to $5000 and persons found guilty should be responsible for paying the full costs of replacing and coordinating the marks.

The existing surveying legislation provided the authority for the establishment and protection of the 1963 Guam Geodetic Triangulation Network. This legislation placed a number of obligations on surveyors that also relate to surveys carried out in the 1993 GGN. To avoid duplicating these requirements and at the same time ensuring the 1993 GGN has legal status the *Legislation Study Report* recommended draft legislation that would:

- provide legal authority for the 1993 GGN;

- establish the new datum and map projection;
- require surveyors to connect surveys to the 1993 GGN;
- allow for the extension of the 1993 GGN in subdivisions;
- set penalties for disturbing or destroying 1993 GGN marks;
- assist in maintaining the 1993 GGN.

It was important that the legislative authority for the 1993 GGN be introduced at the earliest possible time to ensure adequate provisions were in place to protect the marks. The *Legislation Study* containing the draft legislation was completed in August 1994 but there were considerable delays before it became law.

The draft legislation was transmitted from the Governor to the Speaker, Twenty-Second Guam Legislature, on 20th October 1994, with a request to enact it promptly. The subsequent election and formation of the Twenty-Third Guam Legislature contributed to the delays.

During December 1994 and January 1995, the Australian Team Leader and Tertiary Network Expert attended meetings of the Guam Society of Professional Land Surveyors together with the Territorial Surveyor and former Director, DLM. The aim of these meetings was to explain the proposed legislation to the surveyors, answer their questions and concerns, and obtain their support. In general the surveyors strongly supported the project and most of the draft legislation apart from two contentious issues.

The first related to the power of the Territorial Surveyor to question their definition or determination of boundaries, within Proclaimed Survey Areas, to ensure that they meet certain standards. The intention of the draft legislation was that the checking of boundary definition should be seen as part of the checking process to ensure that nothing is overlooked, rather than an attack on the professional integrity of surveyors. It should be noted that some of the problems with the Guam Cadastre could have been prevented if there had been a greater emphasis on the checking of boundary definition.

The other major area of concern was the requirement for surveyors to place new survey marks, for inclusion in the 1993 GGN, on new subdivisions, before the Territorial Surveyor approves the survey plan. There was general agreement with the need to place such marks and for them to be connected to the 1993 GGN by the Territorial Surveyor, however no consensus was reached by the surveyors on who should place the marks. The surveyors expressed valid concerns that final approval of their plans could be delayed because major site works must be completed before the placement of marks. The importance of the survey marks being placed by the surveyor and connected to his survey was stressed. This concept is fundamental to the improvement of the Guam Cadastre as unless new marks are placed and connected to surveys the benefits of the project will not be realised. All new boundaries must be referenced by suitably located survey marks to ensure that boundaries can be reliably and unambiguously retraced in the future. Only in this way will the proliferation of gaps and overlaps be prevented.

Copies of the Legislation Study were provided for Senators Pangelinan and Santos. The Deputy Director, Territorial Surveyor and Australian Team Leader visited Senator Pangelinan in March to explain the proposed legislation and the importance of quick passage

through the Legislature. Senator Pangelinan indicated his continuing support for the project and adoption of the legislation.

3.7.3 Public Hearing

The Australian Team Leader prepared two submissions for presentation to the Public Hearing considering the survey legislation amendments in Bill No. 179. One, prepared for the Director as an introductory address, gave a short overview of the project and need for adoption of the legislation. The other, prepared on behalf of the Territorial Surveyor and the Australian Team Leader, provided a more detailed view of the project, an examination of the draft legislation and arguments in support of each section.

The Public Hearing was conducted by the Committee on Community, Housing & Cultural Affairs on 23rd May 1995. Before the hearing the Australian Team Leader and Tertiary Network Expert visited Senator Pangelinan, a member of the committee, to discuss the legislation and the hearing. The Australian Team Leader, Tertiary Network Expert and Guam Team Leader also visited Senator Santos, Chairman of the committee. This meeting was very useful as it provided the opportunity to explain the reasons for and benefits of the project and the need to enact the legislation to ensure that the marks are protected and the full benefits of the project can be realised.

At the hearing, the opening testimony was made by the former Director, who provided the background to the project and explained the need to establish the network. He emphasised the savings to GovGuam from the contract with the South Australian Government as opposed to the other proposal and the advantages of having consultants on island throughout the project to ensure completion and provide the technology transfer.

The Director made his testimony on behalf of DLM, explaining the benefits of the project and urging adoption of the legislation. As the Territorial Surveyor declined to speak, the Australian Team Leader then presented testimony on behalf of the Territorial Surveyor and himself.

Representatives of the Guam Society of Professional Land Surveyors expressed opposition to some sections of the legislation. Most of the objections related to the powers of the Territorial Surveyor. One other surveyor spoke briefly against the project and expressed his concerns at the increasing powers of the bureaucracy and the Territorial Surveyor.

The hearing concluded after committee members asked a number of questions of those providing testimony.

3.7.4 Public Law No. 23-31

The Territorial Surveyor and Australian Team Leader met with Senator Pangelinan to discuss some suggested amendments to the draft legislation as a result of the Public Hearing. Agreement was reached on amendments to be made before Bill No. 179 went to the Twenty-Third Guam Legislature.

Bill No. 179 was passed with all twenty Senators present voting in favour of the bill on 6th June 1995. Before the Governor signed the legislation it was reviewed by the Australian Team Leader. Two small errors were detected and the Governor was advised. The Governor

signed the bill into law as Public Law No. 23-31 on 27th June and transmitted it back to the Speaker, together with a draft bill to correct the two errors.

A public notice appeared in the *Pacific Daily News* of 26th July 1995 advising that the 1993 Guam Geodetic Network replaced the 1963 Guam Geodetic Triangulation Network and that the whole of Guam was declared a Proclaimed Survey Area.

On 7th August, the Director determined that, apart from work in progress, surveys were to be tied to the 1993 GGN as from 1st September 1995 and that all surveys must be tied to the 1993 GGN as from 1st October 1995. He instructed the Territorial Surveyor to advise all surveyors accordingly.

It should be noted that the preparation of submissions, meetings with Senators and attendance at the Public Hearing were additional services provided by the consultants beyond the requirements of the *Scope of Work.*

3.7.5 Opportunities for Improving the Cadastre

During the course of the Legislation Study, a number of opportunities for improving the cadastre were identified. The following recommendations were made:

- The current legislation covering cadastral surveying in Guam be reviewed with a view to revising and modernising the Survey Law, Survey Regulations and the Manual of Instruction for the Survey of Lands and Preparation of Plans in the Territory of Guam;
- The feasibility of creating a coordinated cadastre for Guam be investigated;
- A Confused Boundary Area Pilot Study be carried out and appropriate legislation prepared;
- Fees be introduced for examining survey plans;
- Review the role and resources of the Survey Division and employ additional staff if required.

To ensure that the full value of the GGN flows on, it is essential that all the issues raised by Mr Kentish in the Legislation Study should be addressed and serious consideration given to implementing some of his recommendations. Some of these matters were discussed extensively during the course of the project and in particular the complete revision of both the existing Survey Law and Survey Manual and execution of a Confused Boundary Area Pilot Study.

3.7.5.1 Revision of Survey Law & Survey Manual

The 1993 GGN will provide the basis for preventing the proliferation of future gaps and overlaps provided that it is used properly and surveyors are obliged to comply with the requirements of Public Law 23-31. However to complement these changes it is recommended that the entire Survey Law and Manual should be revised to bring all aspects of cadastral surveying on Guam, including plan examination, up to date.

Unless DLM is prepared to invest in the injection of new techniques and ideas it will not achieve the desired result and take the territory's surveying practices into the twenty-first

century to complement its state-of-the-art geodetic network and realise the full potential of the 1993 GGN. To effectively revise the law and manual it is suggested that DLM should utilise the assistance of a suitably qualified consultant with appropriate expertise in modern surveying techniques who would coordinate the local input. It is suggested that such expertise should be sought off-island to ensure the injection of new ideas.

DENR prepared a draft proposal and provided an indicative costing to undertake such a revision which was discussed with DLM management during the project.

3.7.5.2 Confused Boundary Area Pilot Study

The implementation of a Pilot Study in a Confused Boundary Area where there are known to be gaps and overlaps and uncertainty about the extent of ownership is essential if appropriate survey and legal procedures are to be developed as a model for the resolution of all such problems throughout Guam. It is imperative that techniques are adopted which will resolve these problems with a minimum of fuss and without the reversion to expensive litigation and creation of bad feelings between neighbours. Only with the security of tenure that comes from security of boundaries can citizens and developers invest with confidence in their properties. Litigation is both costly and time consuming and can delay development for years. The South Australian experience has shown that boundary problems can be resolved to the satisfaction of more than 99.9% of owners in Confused Boundary Areas without resort to litigation.

The project to upgrade the territory's geodetic network was largely a result of the serious problems with the cadastre and in particular the gaps and overlaps that have resulted in some areas from the poor state of the 1963 GGTN. The successful completion of the project provides the opportunity to start resolving Guam's boundary problems. This opportunity must be taken if the maximum benefit is to be derived from the new network.

An opportunity exists to combine the Pilot Study with the ***Harmon 2000*** project. This would enable a resolution of the serious boundary problems that are an impediment to the ordered redevelopment of this important area. There seems little point in pursuing this project if security of tenure and boundaries cannot be guaranteed.

DLM was provided with indicative costing for DENR to implement a Pilot Study in conjunction with DLM.

3.7.5.3 Review of Survey Division

The Legislation Study drew attention to the need to review the role and resources of Survey Division to ensure that Guam's cadastral system is properly maintained and improved. It stressed the importance of Survey Division being staffed with appropriately qualified and experienced personnel. This need is made even greater by the creation of the Geodetic Section which will be responsible for extension and maintenance of the 1993 GGN and for the development of GPS techniques for other survey purposes.

The study highlighted the concerns over the obvious lack of well qualified registered surveyors and suggested that the situation should be addressed as a matter of urgency. It is imperative that DLM should seriously consider appointing at least one and preferably two professionally qualified surveyors with an up-to-date knowledge of modern survey techniques and procedures. Ideally they should be drawn from overseas where they have had

extensive exposure to a variety of modern techniques so that they can guide DLM and the private sector in the development of modern and appropriate procedures. It is suggested that one appointee should be well versed in geodetic surveying and GPS.

3.8 Secondary & Tertiary Networks (Parts I, II & III)

Establishment of the Secondary and Tertiary Network was divided into three approximately equal components:

3.8.1 Expected Outputs

The Scope of Work stipulated the following total outputs for these components of the project:

- design and construction of the Secondary and Tertiary Network (consisting of approximately 2200 marks) to the specifications in the Scope of Work;
- observation of approximately 200 Secondary Network stations to comply with NGS specifications for Order 2-I (20 parts per million - 95% confidence level), using kinematic, static or fast static GPS methods;
- observation of approximately 2000 Tertiary Network stations to comply with NGS specifications for Order 2-II (50 parts per million - 95% confidence level), using kinematic, static or fast static GPS methods;
- observations to any Tertiary Network stations, unable to be surveyed with GPS, using conventional survey techniques;
- connection to existing 1963 GGTN marks within the areas covered by the secondary and tertiary network;
- preparation of survey mark location cards for all marks;
- training of a minimum of three GovGuam personnel and one person from the Commonwealth of the Northern Marianas in field reconnaissance, static, fast static and kinematic GPS techniques;
- two GovGuam personnel will have received training in the processing and adjustment of GPS data;
- reduced and processed data to provide preliminary coordinates for all marks;
- a minimally constrained adjustment for these secondary and tertiary marks;
- Network Diagrams produced for the secondary network;
- Survey Mark Index produced;
- A brochure will be prepared during the final on-island operational stage of the project to provide an explanation of the 1993 GGN and the GPS technology used to establish the network. The brochure should be distributed to all potential users of the new network;

- A descriptive plaque will be mounted on an above ground monument, close to the datum monument, to provide information about the project and the 1993 GGN.

3.8.2 Implementation

It was decided that the best approach for implementation of the Secondary and Tertiary Networks was to commence in the north of the island and work south. The municipalities of Dededo and Yigo comprised Part I, Part II was made up of the central municipalities of Tamuning, Barrigada, Mangilao, Mongmong-Toto-Maite and Agana. The remaining municipalities are in Part III. The table below shows the number of second and third order marks on each part of the project.

	Second Order	Third Order	Total	New Marks
Part I	73	875	948	789
Part II	49	766	815	744
Part III	94	744	838	667
Totals	216	2385	2601	2200

Table 1 - Mark Summary

3.8.2.1 Secondary & Tertiary Network (Part I)

Before reconnaissance could start it was necessary to relocate as many as possible of the surviving 1963 GGTN marks. This activity was scheduled for completion by DLM before implementation of Phase II, however it was necessary to use project resources to locate and mark all surviving stations at this stage. Reconnaissance for Part I commenced two weeks earlier than scheduled to enable sufficient locations to be selected and the necessary approvals obtained from the relevant utility agencies for the monumentation to proceed in accordance with the *Scope of Work*. After sites were selected for the new marks each of the utility agencies, including the Navy and Guam Cable TV, were provided with maps and detail sketches of the locations to determine if any of them coincided with underground services and needed to be relocated.

It had become obvious by this stage that the approval process was going to be much more time consuming than originally envisaged by the consultants when preparing the project proposal, not only in the time for preparation and delivery of information to the agencies and follow-ups, but also for the agencies to grant approvals. Although obtaining approvals was specified as a DLM responsibility in the *Phase I Final Report*, the project took on this responsibility because of DLM's limited resources and the need to maintain control of the process to minimise delays.

Requests for approvals for mark sites resulted in a varying response. Most of the agencies provided a satisfactory service, however all agencies caused delays at some time. Public Utility Agency of Guam advised part way through the component that no more approvals were required from their agency.

Survey Mark Location Cards were produced for all the new GGN marks and for existing marks that were not within the asphalt pavement. The locations of all marks were plotted on copies of the orthophoto maps together with road and street names. This set of maps will be a valuable permanent record of tertiary network activity. Copies of these maps were submitted to the agencies for site approvals and were used for project planning.

Monumentation on Part I was undertaken jointly by DLM staff and private contract. DLM constructed a total of 488 marks and the contractor, Mr. Remi T. De Castro constructed 301 marks. Both the contractor and the DLM team made extensive use of pre-cast marks. The DLM team initially made use of the four moulds brought from DENR, later they were supplemented by eight moulds purchased by DLM. All marks constructed by contract were quality assured by the project team, only a few minor problems were encountered and these were resolved satisfactorily.

The DLM monumentation team had difficulty in maintaining the required rate of construction from the start. The efficiency of the DLM team was affected by the weather, time spent providing materials to both DLM and the private contractor, and the making of pre-cast marks. Although a second monumentation team was to be employed during September 1994, the unavailability of a second vehicle, which was awaiting repairs, and continued absenteeism effectively restricted monumentation to one party for most of the month. This resulted in a critical situation with the likelihood that monumentation would not be completed on schedule and the possibility of delays to the observation program.

The then Director allocated additional resources, spoke to the team members about the intolerable absenteeism and requested that they make a commitment to the project. The intervention of the Director resulted in a dramatic improvement in attendance and attitudes and the monumentation was effectively completed on schedule at the end of October.

Where marks were placed in concrete sidewalks it was necessary to cut a hole in the sidewalk using the concrete cutting saw purchased for the project. All cutting was done by a DLM team, whether the marks were to be constructed by DLM or the contractor.

The three GPS vehicles were set up for observations with the installation of internal mounts for the receivers, external mounts for the antennae, and signs and flashing lights for safety. Observations for the 73 secondary stations were completed using fast static GPS techniques. Fast static and kinematic techniques were used to coordinate the 875 tertiary marks on Part I.

The data was processed and preliminary adjustments undertaken to ensure that the specifications had been met. Preliminary coordinates were provided for input into the Guam Survey Mark System.

Training was ongoing throughout the component, with DLM staff receiving training in each aspect of the component, including reconnaissance, observations and processing of data. There was no participation by personnel from the CNMI.

3.8.2.2 Secondary & Tertiary Network (Part II)

A search was made for all surviving 1963 GGTN marks, including bench marks, in the Part II Tertiary Network area during the first week of November. As a consequence of the extensive road reconstruction within this area only 39 old marks were found.

Reconnaissance activities commenced about three weeks ahead of schedule, to enable sufficient clearances to be obtained for monumentation to start on schedule.

The utility agencies generally provided an efficient approval service during this part of the project, although some delays were experienced particularly between Christmas and New Year. However, the worst delays were at the end of the component when the US Navy were unacceptably slow in approving the last two requests for mark locations, taking up to six weeks for a few marks

Survey Mark Location Cards were produced as in Part I and the location of all marks plotted on the copies of the orthophoto maps.

Because of limited DLM resources, the construction of all the monuments on Part II was contracted to Mr. Remi T. De Castro. Certain marks were not constructed in accordance with the schedule and monumentation was completed a month behind schedule which in turn delayed completion of the GPS observations.

Numerous instances of sub-standard construction were encountered during the quality assurance checking and had to be rectified by the contractor. This resulted in an unacceptably large number of marks requiring a second quality assurance visit, which wasted an appreciable amount of time.

With the change of Administration, in January 1995, restrictions were imposed on the use of vehicles, preventing DLM staff from taking vehicles home. This resulted in a substantial loss of productive time as vehicles had to be loaded and unloaded each day, collected from the Mass Transit Depot and returned at the end of the day. Vehicle unserviceability also contributed significantly to lost time.

Fast static GPS observations were made to the 49 secondary marks on Part II while a combination of fast static and kinematic observations were used for the 766 tertiary points. Completion of the GPS observations was delayed for two weeks by the following:

- Loss of time each day in collecting vehicles from, and returning to the Mass Transit Depot;
- Vehicle unserviceability;
- Marks not constructed as scheduled;
- Loss of personnel.

The data was processed and preliminary adjustments undertaken to ensure that the specifications had been met. Preliminary coordinates were provided for input into the Guam Survey Mark System.

Training was ongoing throughout the component, with DLM staff receiving training in each aspect of the component. Mr Wence Aquino from CNMI's Department of Lands & Natural Resources joined the project during February and March 1995. He was able to participate in each facet of the project during the two months he was with the project and gained a broad understanding of both the project and GPS.

3.8.2.3 Secondary & Tertiary Network (Part III)

Reconnaissance for the surviving 1963 GGTN marks in Part III was carried out before undertaking the reconnaissance for new mark locations. The network design commenced five weeks early to ensure sufficient clearances would be obtained for monumentation to start on schedule. Reconnaissance was completed on schedule for the 667 new secondary and tertiary marks in this part of the project.

Although there were some delays in securing approvals from the utility agencies during Part III, most agencies provided a satisfactory service which did not delay the monumentation.

The location of all marks were plotted on the copies of the orthophoto maps and Survey Mark Location Cards were prepared as in the previous components.

The Director decided that all monumentation for Part III would be undertaken by DLM and made a commitment to provide the necessary resources, indicating that manpower might be obtained from Department of Correctional Services (DOC). Subsequently it was agreed that two monumentation teams would be provided by DLM and that the pre-cast marks would be constructed by Department of Public Works (DPW). However DPW failed to meet their obligations and eventually the marks were made at DOC. The uncertainty wasted a considerable time in trying to resolve the matter to the satisfaction of the consultants and in the delivery and transfer of materials to DPW and DOC.

Although there was some confusion within DOC as to how many marks were to be manufactured, this was eventually resolved and construction at DOC was successful. The marks were well made and DLM made a considerable saving on the resources required for monumentation. Despite delays from vehicle problems and some staff absenteeism the monumentation was completed on schedule.

GPS observations to the 94 secondary monuments were completed using fast static techniques. A combination of fast static and kinematic observations were used for the 744 tertiary points. Despite delays caused by the difficult communications in the south of the island and problems with vehicles the GPS observations for Part III were completed on schedule.

After processing of data, preliminary adjustments were completed to ensure that the specifications had been met. Preliminary coordinates for the final part of the secondary and tertiary networks were provided for input into the Guam Survey Mark System before the consultants left Guam.

Training was again ongoing throughout the component, with DLM staff receiving training in each aspect of the component. During this last component DLM staff were given greater responsibility for day to day operations to ensure that they had achieved a satisfactory level of expertise.

3.8.2.4 Awareness Brochure

The Awareness Brochure is intended to provide potential users of the 1993 GGN with an explanation of the geodetic survey and the GPS technology utilised on the project. It presents information on Guam's new geodetic datum, the Guam Map Grid and the GSMS. A

draft was prepared before the completion of on-island activities. The brochure content could not be finalised until after completion of the final adjustments and determination of transformation parameters.

The brochure is provided as a Word for Windows document together with bitmap files for the graphics. All files are on the backup tape with the final data.

3.8.2.5 Adelup Point Datum Monument

The *Scope of Work* specified that the above ground monument on which the descriptive plaque would be mounted was to be constructed during the Secondary & Tertiary Network Part III Component. However it was decided to bring this activity forward to maximise the benefit to the project of the attendant publicity generated by unveiling the monument.

The monument and descriptive plaque were designed and installation completed by the end of August 1994. DLM organised construction of the monument and pathways while the descriptive plaque was cast in Australia by DENR. The Director secured some original Latte Stones from the Department of Parks and Recreation which were erected close to the datum monument. The ribbon cutting and unveiling ceremony took place at Adelup on 8th September 1994.

3.8.3 Variations

The variations from the expected outputs were as follows

- The CNMI's Department of Lands and Natural Resources only sent a member of their staff to participate in the Part II component.
- No Network Diagrams were produced for the Secondary Network. DLM's GIS produced a Network Diagram for the Primary Network and has the capability to produce one for the Secondary Network if so desired.
- As indicated in 3.5.3 above, it was decided that the Survey Mark Index would be produced as overlays for the ortho-photo maps. These will be produced by DLM's GIS Division. By the end of the project, GIS had produced a draft overlay to enable a decision to be made on the final format. It was decided that it was appropriate for Mr. Tom Torres, Guam Team Leader and Supervisor, Geodetic Section, to determine the preferred format and liaise with GIS Division on this matter. The copies of the orthophoto maps used during the project have the location of all GGN marks plotted, and will be used as an interim index.

3.9 Other Matters

Other matters of relevance to implementation of the project follow.

3.9.1 Materials

It had become obvious during Part I that the estimate of the numbers of droppers and covers required for the project was not going to match reality for two reasons. First, contrary to pre-project expectations, droppers were found more suitable for witnessing survey marks in semi-urban and industrial areas. Second, the actions of Guam Power Authority (GPA) affected the use of covers. It was envisaged that most marks in urban areas would be placed

in concrete sidewalks which would have necessitated the use of covers. Such placement was preferred by the project, local surveyors and Department of Public Works (DPW). However GPA's Transmission and Dispatch Branch did not allow many marks to be placed in sidewalks. This was beyond the control of the consultants and DENR.

Accordingly, it was suggested that DLM purchase both the additional materials and enough materials to cover DLM's requirements for about five years. DLM would require ongoing supplies of witnessing and monumentation materials, for both maintenance activities and extension of the network. All materials left at the end of the project would then remain with DLM, providing all materials needed by DLM at a considerable saving. Purchase and shipping costs were provided by DENR.

DLM declined to accept this offer and therefore DENR purchased sufficient droppers and witness plates to complete the project. Because of the delay in resolving this matter, some droppers were placed without witness plates on Part II, and the points had to be revisited to affix the witness plates.

The purchase of additional materials was eventually resolved in August 1995 and under a contract amendment DENR agreed to purchase the materials in Australia on behalf of DLM and ship to Guam. Under this arrangement DLM also agreed to pay for the additional materials purchased in February 1995 and all materials left at the end of the project became the property of DLM. DENR has ordered 600 of each of the following; brass disks, droppers and witness plates.

3.9.2 Communications

While good communications are essential for efficient static GPS operations, they are an absolute necessity for the conduct of any fast static and kinematic GPS operations. The provision of communications between GPS parties was a DLM responsibility. It was assumed that Survey Division's radios would provide a suitable level of communication between the GPS parties, but it was discovered this was not to be the case in the southern part of the island. The anticipated communication problem was brought to DLM's attention at least six months before GPS observations were to commence on Part III of the project.

Two options were eventually pursued by DLM. The first was the installation of a capability within the existing DLM Motorola radios that would allow direct radio to radio communications without a repeater station. This option was tried but proved to be ineffective unless direct line of sight conditions existed. A second option using a set of Civil Defence radios was tried, but little was gained from the exercise apart from frustration. The radios proved no better than the DLM radios and accordingly some of the observations in Part III were conducted under extremely difficult communication conditions, seriously affecting productivity.

3.9.3 Safety Issues

Although safety issues were carefully addressed during Phase I of the project they remained a problem throughout the project. DPW are responsible for safety on road work sites and asked that their safety requirements were complied with. While this would appear reasonable, DPW appeared to change their requirements. The point of concern was the advice given at a meeting in July 1994, that signs and cones must be placed at set distances from the job site for the GPS observations as well as monumentation activities in addition to

the wearing of safety vests and the provision of warning signs and flashing lights on vehicles. This was seen as impractical, with kinematic GPS observations taking two minutes at each site, as more time would be spent placing signs than doing the observations. At a subsequent meeting in August the DPW safety Officer, Mr Dave Camacho, agreed that the measures proposed for the GPS observations in the Phase I Report were reasonable. Vehicles were to be equipped with flashing lights and signs, hazard lights were to be used, staff were to wear safety vests at all times and traffic cones would be used where appropriate.

Signs were mounted on the rear of the roof racks of the GPS vehicles and inspected by Mr Camacho who gave verbal approval for the setup. However written approval was never obtained despite repeated requests by DLM and promises from DPW.

During the Part II and III observations GPS teams were stopped on a number of occasions by both DPW inspectors and the police because they were not using signs and cones. The absence of written proof that they were complying with the agreed safety measures made these situations difficult for those concerned. As DLM will have an ongoing need to conduct mobile GPS operations it is important that further efforts are made to secure written approval from DPW.

3.9.4 Equipment

DENR purchased the GPS, survey, computing and ancillary equipment necessary for the project. This equipment was turned over to DLM at conclusion of the project. It is important that this equipment is retained by the Geodetic Section for use in extending and maintaining the network. DLM should budget for maintenance and replacement of this equipment if the department is to maintain its ability to conduct GPS operations, maintain the network and ensure sustainability of the project.

It had been intended that DENR would purchase simple 2-way radios to be used by the reconnaissance parties over quite short distances. After discussion with DLM team members and the Territorial Surveyor it was decided that such radios would have little use and it would be better to purchase a more sophisticated radio compatible with the DLM radios. Accordingly a Motorola radio, compatible with the DLM radios, was purchased

3.9.4.1 Maintenance Agreements

To ensure that the GPS equipment and software was maintained throughout the project, extended warranties and upgrade agreements were purchased as follows:

- One year hardware warranty extension 1996; Expiry 25th March
- One year software upgrade (Trimvec) 1995; Expiry 25th March
- Four year firmware update 1998; Expiry 25th March
- Four year software update (GPSurvey) Expiry 25th March 1998.

A copy of the letter from Bench Mark Positioning Services indicating the details above is included as Appendix 5.

The Trimble agent that is responsible for the warranties and maintenance agreements is:

Bench Mark Positioning Services,
100 Carrington Street,
ADELAIDE,
SOUTH AUSTRALIA, 5000
Ph 618 - 232 5405
Fax 618 - 224 0600

Bench Mark has been advised that the equipment has been transferred to DLM and should make contact with DLM in the near future.

The GeoLab geodetic adjustment software (Licence No. 9312002) was purchased from Leica Instruments (Australia) and was covered by a maintenance agreement for the first year. In order to receive software upgrades it will be necessary to renew the maintenance agreement with Leica. Leica recently advised that GeoLab V2.6 would be released in the near future. This upgrade will enable kinematic data reduced with GPSurvey V2 to be adjusted. Without this upgrade it is not possible to utilise the improved kinematic processor and DLM will be restricted to fast static techniques. The contact details for Leica are as follows:

Leica Instruments Pty Limited,
45 Epping Road,
NORTH RYDE,
NEW SOUTH WALES,
AUSTRALIA, 2113
Ph 612 - 888 7122
Fax 612 - 888 7526

Leica have been advised that the software has been transferred to DLM and should make contact with DLM in the near future.

3.9.5 Vehicles

The provision of project vehicles was a DLM responsibility and DLM had made a commitment to purchase new vehicles for use on the project. All facets of a project such as the 1993 GGN rely upon sufficient suitably equipped and adequately maintained vehicles to ensure that operations are not delayed. Unfortunately DLM was unable to meet this requirement. At various times throughout the project it was difficult to secure the required number of vehicles and most of the project vehicles were in a poor state of repair. Vehicles were often off the road for extended periods, sometimes as long as four weeks, awaiting or undergoing repairs or the replacement of necessary items such as tyres and batteries. They were often unroadworthy, various vehicles failed the annual safety checks and one vehicle was never properly equipped with the tools and jack required to change a wheel. Considerable time was wasted because of DLM's failure to provide adequate vehicles for the project.

3.9.6 South Australian Management/Study Tour

The Management/Study Tour took place from 15th - 25th October 1994 in Adelaide, South Australia. The three participants, the Territorial Surveyor, Mr Bob Kono and Mr. Marcel Camacho, were able to look at all aspects of the South Australian Department of Environment & Natural Resources related to survey, land administration, mapping and LIS. Unfortunately the Director was unable to accompany the tour as had been planned. There was also the opportunity to look at other relevant government functions and South Australian initiatives of possible future benefit to Guam.

3.9.7 5th South East Asian & 36th Australian Surveyors Congress

The Congress was held in Singapore from 16th to 20th July 1995. A paper written by the, Australian Team Leader and Tertiary Network Expert with some input from the Territorial Surveyor entitled: *The 1993 Guam Geodetic Network - A GPS Network for the 21st Century,* was presented at the Congress.

The Congress was attended by the Director, Territorial Surveyor and Australian Team Leader. Presentation of the paper and attendance at the Congress provided an excellent opportunity for Guam to publicise its achievements with this important and historic project and to make contacts with surveyors from throughout the region.

Guam's survey community should be encouraged to become more involved with their fellow professionals in the region. Such activities and contacts will foster professional development and the introduction of more modern survey techniques and practices.

3.9.8 Provision of Data to NGS

The *Scope of Work* addressed the matter of providing data for the Primary Network to NGS. It stipulated that if data was to be provided, then DLM had to obtain the software and documentation from NGS to allow an assessment of the resources required to convert the data to the "Blue Book" format, and if necessary allocate those resources.

The software and documentation wasn't secured until February 1995. As DLM were having difficulty providing the minimum resources to complete the project it was not deemed worthwhile for the consultants to waste valuable time assessing resources necessary for "Blue Booking". This matter may be considered by DLM as resources become available.

3.9.9 Manuals

The following manuals were prepared by DENR during the project:

- *Guam Survey Mark System - User Manual;*
- *Global Positioning System - Operational Manual;*
- *Tertiary Network - Procedure Manual.*

It should be noted that the preparation of the *Tertiary Network - Procedure Manual* was not a requirement under the *Scope of Work*. The Tertiary Network Expert devoted very many hours of his own time to the production of a very comprehensive manual to be used by the Geodetic Section.

3.9.10 Reports

The consultants made detailed and extensive reporting on each aspect of the project. The following reports were prepared by DENR before the project commenced:

- *Land Information Management Strategy;*
- *Proposal to Establish a Geodetic Network for Guam.*

The following reports were prepared during implementation of the project:

- *Phase I Final Report;*
- *Phase II Scope of Work;*
- *Mark Maintenance Report;*
- *Legislation Study;*
- *Guam Survey Mark System - Detailed System Design;*
- *Guam Survey Mark System - Implementation Strategy;*
- *Guam Survey Mark System - Final Report;*
- *Progress Report - November 1994;*
- *Analysis & Assessment of the 1993 Guam Geodetic Network.*

In addition a Monthly Report was prepared at the end of each month of the project with the exception of February 1995 and July 1995. The March 1995 report covered a two month period. These reports detailed progress on the project and any problems that were encountered.

4.1 Introduction

This unique project has replaced the existing inadequate triangulation network with a world standard high precision network and provided the supporting infrastructure within the short period of less than two years. It is unique in that the entire geodetic network, from the primary to the tertiary level has been established in one operation using the same technology.

This section analyses the results, looks at the problems encountered on the project, and addresses issues such as effectiveness, training and sustainability. It concludes with some recommendations for consideration by DLM.

4.2 Datum and Map Projection

The *Phase I Final Report* recommended the adoption of the WGS84 (World Geodetic System of 1984) geodetic datum for Guam. This is a geocentric datum which has been adopted by a growing number of countries because it is the GPS satellite datum. The report further recommended that it be introduced to Guam through the Philippine Sea Plate Survey.

Subsequently NGS advised that they had conducted a high accuracy GPS survey connected to fiducial stations in Hawaii with coordinates available on the NAD83 (North American Datum of 1983) geodetic datum which is very similar to WGS84. NAD83 uses the GRS80 spheroid as a reference figure. NGS sought comment from DLM on the designation of the reference system for Guam and suggested that it should be called the Pacific Reference System of 1993. After consultation with his DENR consultants, the former Director decided that NAD83 would be more appropriate for Guam than WGS84 and recommended to NGS that it be designated as such. NGS accepted this recommendation and provided data from their adjustment in January 1995, including A Order coordinates for station **ARP GUM** (0014).

The *Phase I Final Report* recommended the adoption of a local Transverse Mercator (LTM) map grid for Guam, known as the Guam Map Grid, to overcome problems with the existing map grid. This was seen as a more practical solution than adopting the Universal Transverse Mercator (UTM) system.

NGS has been advised of this decision and taken the appropriate steps to include the Guam Map Grid in their software and publications.

Public Law 23-31 provides legal authority for the new datum and map projection.

4.3 Final Adjustment

The final adjustment of all the data was undertaken by the Australian Team Leader in Australia after completion of the on-island components. The Project Geodesist, Mr Andrew Jones, provided an independent assessment and analysis of the final adjustment. Full details are provided in his report, *Analysis & Assessment of the 1993 Guam Geodetic Network.* A brief summary follows.

The 1993 GGN has been coordinated using precise GPS relative positioning observations. Baselines were processed using the Trimble software and adjustments undertaken using

GeoLab. Separate adjustments were made for each of the primary, secondary and three stages of the tertiary networks.

The following coordinate files are provided for input into the SMDB:

PRIM.NAD	Primary Network	NAD 83 - Geographicals & Sph. Heights
PRIM.GMG	Primary Network	Guam Map Grid - Northings, Eastings
SEC.NAD	Secondary Network	NAD 83 - Geographicals & Sph. Heights
SEC.GMG	Secondary Network	Guam Map Grid - Northings, Eastings
TER2.NAD	Tertiary Network (Part I)	NAD 83 - Geographicals & Sph. Heights
TER2.GMG	Tertiary Network (Part I)	Guam Map Grid - Northings, Eastings
TER3.NAD	Tertiary Network (Part II)	NAD 83 - Geographicals & Sph. Heights
TER3.GMG	Tertiary Network (Part II)	Guam Map Grid - Northings, Eastings
TER4.NAD	Tertiary Network (Part III)	NAD 83 - Geographicals & Sph. Heights
TER4.GMG	Tertiary Network (Part III)	Guam Map Grid - Northings, Eastings

4.3.1 Primary Network

The Primary Network Adjustment included four secondary stations observed at the same time giving a total of 32 stations in the adjustment. The network was constrained to **ARP GUM** (0014), an A Order station coordinated by NGS in 1993. Five stations were observed to B Order specifications, **URUNO** (0004), **AAFB** (0008), **DANDAN** (0019), **TOGUAN** (0022) & **ADOFGAN** (0025). Each of these stations and **ARP GUM** (0014) were occupied for a minimum of three sessions with each session a minimum of six hours and some observations up to 24 hours. All other primary stations were connected to the above by a minimum of three sessions of at least two hours duration.

The network exhibits a high level of redundancy. Analysis of the final adjustment confirms that the required specifications have been achieved and in most cases have been exceeded.

4.3.2 Secondary Network

The Secondary Network Adjustment comprised 213 free stations constrained to 29 stations from the Primary Adjustment. One of these free stations was a reference mark for **FADIAN**. Accordingly there are 216 stations in the Secondary Network. The network features conventional triangle geometry and was observed using fast static GPS techniques. Observations were generally of 20 minutes duration. All stations were occupied in a minimum of two sessions and most a minimum of three.

A high level of redundancy resulted from the observation program. Analysis of the final adjustment confirms that the required specification of Order 2-I for 200 stations has been

easily met. Relative accuracies for all of the 216 secondary stations meet and in most cases exceed these specifications.

4.3.3 Tertiary Networks

The Tertiary Network comprising 2385 stations was divided into three stages for both observation and processing purposes. Each tertiary station was directly surveyed from either a primary or secondary station and there were very few direct connections between the tertiary stations. Both fast static and kinematic observations were used, however the majority of observations were fast static and of about five minutes duration.

The level of redundancy for the Tertiary Networks was substantially lower than for the higher order networks but was nevertheless in accordance with accepted practice. Analysis of the adjustments indicate that the relative accuracies either meet or exceed the specified requirements for Order 2-II.

4.3.4 Conclusion

The Project Geodesist has concluded the following:

- The 1993 GGN has been appropriately designed, measured and computed at all levels of the network hierarchy;
- The absolute and relative accuracies of the networks as expressed by the formal statistics either appropriately represent or slightly understate the actual situation;
- The 1993 GGN primary network is a high precision network which is capable of supporting all foreseeable geodetic activities on Guam, including local geophysical monitoring;
- The 1993 GGN tertiary network is a sound general purpose survey network which will satisfactorily support routine land administration and surveying activities throughout the settled areas of the island.

4.4 Determination of Transformation Parameters

As previously indicated the 1993 GGN has adopted a new datum and map projection for Guam. To relate the 1963 GGTN to the 1993 GGN it was necessary to develop transformation parameters. To be able to generate reliable values requires sufficient stations with values in both systems. With the exception of a few very remote points, a diligent search was made for all 1963 stations as part of the project. Fortunately a large number of 1963 stations were recovered and subsequently observed, enabling the determination of reliable parameters. A complete description and analysis of the parameter determination is contained within the *Analysis and Assessment of the 1993 Guam Geodetic Network* prepared by the Project Geodesist.

4.4.1 Datum Transformation Parameters - 1963 GGTN to 1993 GGN

Initially two trial sets of transformation parameters were developed using:

1. The 1963 primary and secondary stations only;
2. All available 1963 primary, secondary and tertiary stations.

In both cases, the latitudes and longitudes were taken directly from the 1963 GGTN coordinate listings and from the 1993 GPS survey. Spheroidal heights for the 1993 stations were also taken directly from the GPS survey. However spheroidal heights for the 1963 coordinates were not available due to an absence of geoidal mapping relative to the local datum. In addition, very few of the stations had levelled heights.

To overcome these difficulties, 'pseudo-spheroidal' heights were derived by subtracting OSU91A geoid-spheroid separations from the GPS spheroidal heights. It should be noted that these 'pseudo-spheroidal' heights were in fact orthometric heights. By adopting them as spheroidal heights, an assumption was made that the OSU91A geoid and the Clarke 1866 spheroid were coincident. This was a reasonable initial hypothesis given that local datums are invariably defined such that they minimise the geoid-spheroid separations in a nominated area of interest.

The determination based on the 1963 primary and secondary stations produced encouraging results with post-transformation horizontal residuals less than 0.05m in most cases, supporting the earlier assessment that the 1963 triangulation was of high quality. The height residuals were much larger, often exceeding 0.2m, suggesting an inconsistency between the shape of the OSU91A geoid and the Clarke 1866 spheroid.

The parameters derived from all available 1963 stations were significantly different. The horizontal residuals for the 1963 primary and secondary stations were similar to those generated above, however a significant number of 1963 tertiary stations produced large residuals. These residuals often displayed significant changes in magnitude and direction over relatively short distances and there are radically different systematic trends on different parts of the island.

Considering that both the 1963 Primary and Secondary Networks, and the 1993 GGN have been precisely observed, it was resolved that island wide transformation parameters should be developed using only these stations to enable both geodetic datums to be related as precisely as possible.

In areas where local distortions in the 1963 Tertiary Network result in unacceptably large residuals that display a local systematic trend it is suggested that consideration be given to developing a series of local transformation parameters to enable 1963 coordinates to be transformed to the 1993 datum. It is suggested that this would best be done using a 2D similarity transformation (solving for two translations, one rotation and a scale factor) between grid coordinates in the two systems. The Project Geodesist has suggested that at least seven sets of local transformation parameters will be needed at some time in the future. It is estimated that about a week would be required to develop such parameters. This would not include time to transform any dependent surveys.

As has been mentioned in 3.5.2 above, the process of transforming DLM's digital data is unlikely to be a simple matter. Transformations are complex procedures requiring a thorough understanding of map projections, geodetic datums, transformations and advanced mathematics, and it is important that DLM either acquires the necessary expertise or engages a consultant to ensure that transformations are reliable. It is imperative that DLM is able to ensure its basic data is reliable and this will only be possible if the transformation process is supervised by someone with the necessary expertise.

To resolve the statistical problem associated with the large height residuals generated during the transformation process it was decided to assume that these residuals are in fact the geoid-spheroid separations between OSU91A and the Clarke spheroid. These values were then applied to the "pseudo-spheroidal" heights and the parameters were generated again. It must be stressed that due to the absence of independently determined 1963 GGTN spheroidal heights, extreme caution should be exercised when transforming heights between the two systems. Heights used in the determination are not compatible with the Guam height datum. The transformation parameters relating the 1963 and 1993 datums are shown in Table 2 below.

Transformation Parameters
1963 GGTN to 1993 GGN

Parameter	Value	SD
Translation X (meters)	201.686	1.484
Translation Y (meters)	66.350	1.276
Translation Z (meters)	457.288	1.115
Rotation X (seconds	2.925	0.041
Rotation Y (seconds)	6.188	0.042
Rotation Z (seconds)	-14.106	0.043
Scale (ppm)	2.327	0.229

Table 2 - Transformation Parameters

Additional global parameters relating 1963 GGTN plane coordinates to the 1993 GGN Guam Map Grid have been developed and are shown in Table 3 below. The parameters were generated by means of a four-parameter similarity transform.

Transformation Parameters
1963 GGTN Plane Coordinates to 1993 GGN Guam Map Grid

Parameter	Value	SD
Translation East (meters)	50127.431	0.020
Translation North (meters)	147112.108	0.020
Rotation (seconds	1.056	0.058
Scale (ppm)	-6.264	0.281

Table 3 - Transformation Parameters

4.4.2 Datum Transformation Parameters - Old Guam Coordinate Sets to 1993 GGN

During the course of the project, the Territorial Surveyor and private surveyors on Guam requested that the project provide transformation parameters to relate the 1913, 1945 and 1949 networks to the 1993 GGN. The *Scope of Work* didn't make any commitment to provide this information, however the Australian Team Leader undertook to try to provide such parameters provided that sufficient stations from these networks were recovered and observed as part of the 1993 GGN and that sufficient information was also made available.

Despite repeated requests only limited information was ever provided and not until the end of the project. Accordingly an assessment of the available data could not be made until after the completion of on-island activities. This should have been undertaken during the project to avoid any delays to the completion of the final adjustment and determination of transformation parameters.

Attempts were made to generate transformation parameters relating the 1993 GGN to coordinate sets computed in 1913, 1945 and 1949. Few common stations were available for this purpose and the results obtained were of very dubious quality. Consequently, it is considered inadvisable to publish parameters derived from this data.

4.4.3 Determination of Latitude and Longitude from Guam Map Grid Coordinates

The Territorial Surveyor requested that the project provide a table for simple determination of latitude and longitude from Guam Map Grid coordinates. A similar table was available for the 1963 GGTN. Preparation of such a table was not included as an output in the *Scope of Work*, however after discussions between the Australian Team Leader and Project Geodesist it was decided that this extra output could be provided. The table is included as Appendix 4 in the *Analysis and Assessment of the 1993 Guam Geodetic Network.*

It should be noted that the values extracted from this table are approximate and it does not provide the rigorous conversion necessary for any survey purposes that the appropriate transformation software, such as is contained within the GeoLab adjustment package, provides. Geodetic coordinates derived using this table should not be quoted to better than one second. DLM's Survey Division should ensure that all transformations for survey purposes are made within GeoLab, unless other suitable software is acquired.

4.5 Analysis of Vertical Datum

The 1993 GGN has produced a dense network of survey marks which have spheroidal heights related to the NAD83 datum. However a series of points with the same spheroidal height would not necessarily be on a level surface and water could flow between these points. Spheroidal heights are therefore of little practical application for engineering purposes. It is necessary that these heights be converted to orthometric heights if they are to be routinely used.

There are two options available for doing this, being;

1. The derivation of orthometric heights from GPS and the OSU91A geoid (or alternative geoid model), or

2. The derivation of a pseudo-geoid by differencing GPS and levelled heights at common points. A separation contour plan can then be prepared which will allow the interpolation of levelled heights at other GPS stations.

The following need to be considered when selecting the method:

1. There is currently a network of levelled heights around the island. This is connected to the tide gauge at Apra Harbor. The levelling was established in 1963 and appears to be of good quality.

2. Guam is subject to geophysical activity. It is believed that the island subsided by an average of 7 cm following the 1993 earthquake. This subsidence was not uniform but ranged from approximately zero to 12 cm depending on location. This, together with previous geophysical activity, will have degraded the quality of the levelled heights. The extent of this degradation could only be determined by relevelling the existing vertical network.

3. OSU91A geoidal heights have been compared with equivalent quantities derived by differencing GPS heights and levelled heights at 39 stations. The differences between the two quantities range from -0.33 meters to +0.38 meters. It is not clear whether the differences are due to degradation of the levelling, limitations in the OSU91A geoid determination or a combination of the two. A plot is provided showing the differences between the OSU91A values and those derived from GPS/levelling (Appendix 2).

Given the existing extensive usage of the current height datum and the uncertainty regarding the accuracy of the OSU91A geoid values, it is considered preferable that the pseudo-geoid approach be used. A separation contour plan (Appendix 4) has been prepared using 37 of the 39 stations which have been heighted by both GPS and levelling. This plan can be used to interpolate the values of N (geoid-spheroid separation) that can be applied to any future GPS derived heights on Guam to produce orthometric heights. A copy of this plan at a scale of 1:50,000 is provided as a separate item. Stations **0145** and **2117** were not used in the final derivation of the contour plot after an inspection of the initial plot (see Appendix 3), which exhibited serious distortions about these two points. The second plan without these points is more consistent and has been adopted as the geoid map for Guam (Appendix 4).

When utilising the separation contour plan the following must be considered:

1. The contours were derived from a limited number (37) of levelled stations as shown in Appendix 2;

2. The 37 points provide poor coverage of Guam with severe deficiencies in some areas; and

3. The differences between the OSU91A values and those derived from GPS/levelling. (see Appendix 2) could indicate degradation of the levelling or inconsistencies in OSU91A;

Accordingly it is suggested that orthometric heights derived from GPS spheroidal heights and N values derived from the contour plan should not be quoted to better than 0.1 meter.

The following simple formula is used to calculate orthometric heights:

$$H = h - N$$

Where:

H = Orthometric height
h = Spheroidal height
N = Geoid-spheroid separation (or geoidal undulation or geoidal height)

The values of N were derived for each point observed on the 1993 GGN and have been applied to the spheroidal heights to produce a listing of orthometric heights ready for input into the SMDB. The listing is in file GGN_HTS.TXT. A further listing is provided for the 37 points with levelled heights that were used in the derivation of the geoid contour plot, these are in file GGN_MSL.TXT and should be read into the SMDB.

In view of the geophysical activity in 1993, the loss of bench marks from the 1963 levelling network and the elapse of over 30 years since this levelling was carried out it is recommended that serious consideration be given to relevelling the vertical network to determine the extent of degradation due to geophysical activity. If sufficient GPS points are levelled to provide a good coverage over the island then it will be possible to prepare a more accurate separation contour map. Redefinition of the vertical network should include a complete analysis of tidal data from the NGS tide gauge at Apra Harbor.

During the course of the project a comparison of levelled heights with preliminary GPS heights indicated a problem with the levelled heights on two GGTN bench marks on Route 9 (BMs 9-4 & 9-10). The Territorial Surveyor arranged for Survey Division to undertake check levelling to assist in isolating the problem. The levelling confirmed that the published values were in error and also provided levelling on additional GGN stations that assisted in the evaluation of the vertical datum. This episode confirmed the consultants' confidence in GPS when a conflict arises between GPS and conventional survey data. In the consultants experience GPS always proves to be correct provided that sufficient observations have been made using the appropriate procedures for the required precision and that the results have been properly analysed.

4.6 Difficulties & Problems

Throughout the project there were various problems that created delays. The first delays were in occupying the project office space, and in delivery of office equipment and supplies. The delay in providing a facsimile machine, access to direct international dialling and delivery of a suitable photocopier wasted time and created frustration for team members reliant on modern communications. Difficulties were experienced in opening accounts, and problems encountered in purchasing materials and supplies within the GovGuam purchasing procedures.

As mentioned in 3.9.5 above, DLM was unable to provide sufficient suitable vehicles in good mechanical condition throughout the project. The *Work Plan* was based upon the assumption that DLM would provide a certain number of vehicles at all times and failure to do so caused many delays.

The project was at times hampered by the non availability of key staff due to both staff absences and the DLM workload which took staff away from the project. The level of absenteeism combined with vehicle problems affected progress on the Part I monumentation until additional resources were allocated by the Director.

The Part II monumentation which was contracted in total to the private sector created the most problems. There was a high incidence of sub-standard construction requiring attention from the contractor and a significant number of second visits by the project team. Additionally marks were not constructed to the schedule and the monumentation was finished a month behind schedule delaying the completion of observations.

The procedures for obtaining approvals from the utility agencies for the sites selected for the new marks was very time consuming and required the allocation of substantial project resources. At various times during the project significant delays were experienced in the approval process.

The lack of effective communications in the southern part of the island during the Part III observations seriously affected productivity.

Most of the problems highlighted above have caused delays to the project which could have resulted in the project falling very much behind schedule. However the dedication and efforts of the project team, both DLM personnel and consultants, ensured that the on-island activities were completed on schedule. In particular it should be noted that the consultants devoted very long hours to the project including most weekends and holidays.

DLM's failure to provide information about the pre 1963 geodetic networks before completion of the project delayed an assessment of the suitability of the data for generation of additional transformation parameters. This also delayed completion of the final adjustment and determination of transformation parameters.

4.7 Effectiveness

The effectiveness of the project can be judged by a comparative analysis between the project achievements and the outputs specified in the *Scope of Work*. All the on-island components of the project have been completed successfully and all outputs associated with the final adjustment have been completed.

With the exception of a few minor items the project has been completed in compliance with the specified outputs and on schedule. These variations have been noted above. More importantly most of the expected outputs have been exceeded, for example the three extra stations in the Primary Network and better than required relative accuracies for most stations in the Primary and Secondary Networks.

The successful completion of the project despite the problems highlighted above demonstrates the importance of the DENR philosophy behind the project and the approach to implementation. Without the full-time placement on-island of the appropriate consultants, the project would not have been completed on schedule. They demonstrated a commitment to the project regardless of the many difficulties and obstacles. The vital role of the DENR consultants in ensuring successful completion should be considered by DLM when other projects are considered in the future.

4.8 Training

The philosophy behind the South Australian Government's involvement in this and all other projects is that there will be an effective technology transfer to the client agency to ensure long term sustainability. One of the five main objectives of the project was to ***provide***

technology transfer to DLM staff regarding the application of Global Positioning System (GPS) technology to surveying. To enable an effective technology transfer, the training was to be a combination of "on the job" training in all aspects of GPS, and further training in geodetic adjustments in Australia.

DLM personnel were trained in all aspects of the project, including but not limited to the following: reconnaissance, mark construction, completion of field records, GPS observations, downloading, processing and adjustment of GPS data, computer operation, record keeping, data entry into the GSMS and mark maintenance activities.

Before commencing GPS observations for the Primary Network, a two day static observation seminar was held in conjunction with the PSPS team. Similarly at the commencement of the observations for each of the three Tertiary Network components, a week was allocated for training in Fast Static and Kinematic GPS techniques.

"On the job" training, for the duration of the project, ensured that all staff involved in the project can successfully undertake a variety of GPS field operations with a minimum of direction and supervision. Staff were also trained to download observed data from their GPS receivers to a computer for processing. Most Survey Division staff were given the opportunity to spend some time on the project and an effort was made to provide as many as possible with exposure to each facet of the project.

Of particular importance was the comprehensive training of two people in all aspects of GPS surveying. This is essential to the long term sustainability of the technology transfer to DLM. This training was ongoing throughout the project to ensure that the personnel acquired the necessary expertise. As the project progressed the two personnel gradually took on greater responsibility, so that by the end of the project they could run DLM's ongoing GPS and geodetic operations. These two key personnel will undertake the post project training in Australia. The importance of training two people can not be over stressed. Not only does it provide DLM with flexibility but more significantly it is insurance against possible loss of expertise. DLM is investing in GPS technology, upon which it will rely for future extensions of the geodetic network. Therefore it is imperative that the department has sufficient suitably trained staff to ensure that the loss of one key person will not jeopardise future operations.

Under Public Law 23-31, the Director, DLM is mandated to establish the 1993 Guam Geodetic Network (1993 GGN) for use in locating and describing land within the territory. It also requires the Territorial Surveyor to connect new survey monuments placed on all subsequent subdivisions to the 1993 GGN. The legislation stipulates that the 1993 GGN shall be established to specific standards and specifications for GPS surveying. It is therefore imperative that DLM has the necessary expertise to carry out its functions under this legislation without being reliant upon only one person.

The final component of the project will provide further training in geodetic adjustments, of both GPS and conventional observations, for two DLM personnel who have been involved in the observation, reduction and adjustment of the 1993 GGN. This training will be conducted upon completion of the on-island components of the project. It is planned that the training which is to be of three months duration and be conducted within the South Australian DENR will commence in late January 1996.

Soon after the project commenced it became apparent that the training in Australia should be broadened to give the DLM trainees the opportunity to observe and participate in other DENR survey activities of relevance to the establishment and maintenance of DLM's Geodetic Network. In particular, given the importance of mark maintenance to the ongoing sustainability of the 1993 GGN, it is considered essential that the trainees spend sufficient time with the DENR Mark Maintenance Group to gain an understanding and appreciation of how the mark maintenance program operates in South Australia. Accordingly after consultations between the Territorial Surveyor, Australian Team Leader, South Australian Surveyor General and other DENR Survey staff it was decided that the program would be modified to provide a wider exposure to activities associated with establishment and maintenance of the South Australian Geodetic Network. At the same time it was decided to defer the commencement of training from October 1995 to January 1996, to enable DLM to establish its Geodetic Section after completion of the project.

The correct analysis and adjustment of GPS observations is critical. The technology is such that most people could set up the equipment and produce some results with very little training or expertise, but without correct analysis the results could well be garbage and certainly should be regarded as such. The acquisition of the ability to analyse and assess the results is not a trivial matter. It requires extensive surveying experience, training and experience in adjustments, and ideally a tertiary qualification in surveying.

As none of the DLM staff have tertiary qualifications in surveying it was essential that they had extensive experience in the processing and analysis of GPS data throughout the project. To achieve this end it was envisaged that two DLM staff would be assigned for the duration of the project to ensure that they would gradually acquire the necessary expertise and have maximum exposure to the processing, adjustment and analysis of GPS data. They would then be ready for the post project training.

Unfortunately this was not to be the case. In October 1994, Mr Ray Cruz was reassigned to DLM, initially to cover the absence of the Territorial Surveyor and subsequently ongoing staff shortages in Survey Division. Mr Gerard Ragadio replaced Mr Cruz, however the knowledge that Mr Ragadio did not have a permanent position within DLM created a major concern. Eventually his temporary employment was extended beyond the end of the project to cover the training in Australia. It is however important that a permanent position is secured to ensure long term sustainability of the project. Both Mr Torres and Mr Ragadio have demonstrated an excellent attitude towards the project and training, and the ability to manage and undertake all activities associated with the on-going extension and maintenance of the geodetic network. They will benefit significantly from the proposed training in Australia.

DLM should consider the possibility of arranging future training for these two key members of Survey Division. It is suggested that consideration be given to extending their training to full bachelors degree level to equip them with a full mathematical and surveying education.

Aware of the limited survey education opportunities on Guam and the relatively low demand it is suggested that consideration be given to establishing and fostering a relationship between the University of Guam and an off-island university. Such a relationship with a university with a good reputation for its survey education could enable a very much needed improvement in the education of Guam's surveyors.

4.9 Efficiency

Despite the many difficulties and problems encountered on the project, the desire of DENR to complete the project on schedule was never in question. In a period of eighteen months this project has produced a modern, accurate and readily accessible network as the basic spatial framework to support Guam's surveying, land administration and land information needs. Without the use of GPS technology it would have taken many years to complete this task demonstrating the efficiency of GPS. Perhaps more importantly without the determination of the consultants to keep the project on schedule and the support of the DLM project team, the project would still be incomplete.

4.10 Impact

The establishment of a geodetic network has long been recognised as a service to society and as such is provided by government. Although it is difficult to quantify the benefits of a geodetic network, the following benefits are expected from the 1993 GGN.

- It will provide the fundamental support to land surveying, mapping, engineering and related applications, and provides the basis for the integration of all such activities;
- It will provide a homogeneous coordinate system, essential to any Land Information System, enabling the efficient spatial integration of data from many different sources (eg. planning, utility data, survey, mapping, remote sensing, soils and climate to name a few);
- It will control the position of surveys, thus significantly lessening the creation of boundary gaps and overlaps. The Guam experience of confused boundaries, with large gaps and overlaps, is a symptom of the failure to establish and maintain a network at a suitable density and require adequate connections to such a network. The 1993 GGN provides the framework necessary to resolve such existing problems;
- It will lay the framework for the possible introduction of a coordinate based cadastre and surveying system. Studies show significant financial benefits in such a system;
- It will assist in the accurate monitoring of earth movements in seismic and plate tectonic studies.

The success of the project depends upon the degree of comprehension by the potential users of the concepts behind the network and the benefits to be derived from its utilisation. The full benefits will only be realised if GovGuam makes a commitment to maintain and extend the network, and to move forward and initiate actions and projects to improve the quality of the cadastre.

4.11 Sustainability

Sustainability has been stressed throughout the project and this report. The DENR approach to the project was to provide an effective technology transfer to ensure long term sustainability. The project has provided comprehensive training and the necessary infrastructure through the three supporting components of the project to ensure long term sustainability.

To ensure that Guam gains the maximum benefit from the project there must be an ongoing commitment from GovGuam to pursue the goals of the project. Implementation of the Mark Maintenance Program is an ongoing activity. To be successful sufficient resources must be permanently allocated to the program. If not, the network will not be extended into areas of new development and the marks will gradually disappear. Slowly the 1993 GGN will deteriorate until eventually it will be in the same state of disarray as the 1963 GGTN.

At conclusion of the project DLM had set up a Geodetic Section and made a commitment to provide the necessary resources. To ensure that the section is able to operate effectively and efficiently it must be allocated the appropriate level of resources in the form of personnel, office space, furniture, equipment, vehicles and ongoing financial support. To maintain its GPS and other capabilities, equipment must be maintained in working order and replaced as necessary. The section should initially have a minimum of four personnel to enable it to carry out its functions. The staff allocation should be reviewed after the section is properly established and the training in Australia is completed. At this time Mr Torres will have a better appreciation of the sections workload and will have experienced similar functions within DENR.

Critical to sustainability of the technology transfer is retention of the personnel who have received training and who are indispensable to DLM's ongoing GPS, geodetic and mark maintenance activities. Their importance and potential must be recognised by appointment to positions at a suitable level or the reclassification of their existing positions. DLM cannot afford to lose key staff to other organisations after its expenditure on their training.

4.12 Future Opportunities

To obtain the maximum possible benefit from the project there must be a commitment to proper utilisation of the network and an overhaul of survey practices in Guam. Throughout the project a number of areas have been identified where DLM can introduce new initiatives. The following were identified as part of the *Legislation Study*:

- Review of Guam Survey Law, Survey Regulations and the Manual of Instruction for the Survey of Lands and Preparation of Plans in the Territory of Guam;
- The feasibility of creating a coordinated cadastre for Guam be investigated;
- A Confused Boundary Area Pilot Study be carried out and appropriate legislation prepared;
- Fees be introduced for examining survey plans;
- Review the role and resources of the Survey Division and employ additional staff if required.

Unless some of these initiatives are pursued the full benefits and opportunities available from the project cannot be realised. The security of tenure and boundaries reliant on an unambiguous cadastre will result in an improved land administration system. The benefits will then flow through to all areas of society as only with this security of tenure will citizens invest in appropriate development.

DLM now has the equipment and the capability to undertake GPS surveys to either extend the 1993 GGN as necessary or for other survey purposes as appropriate. The level of

expertise acquired by the DLM GGN staff is without equal on Guam and throughout the region. GPS is the surveying technology of the future. It provides the ability to rapidly conduct surveys to a much higher level of precision than has been easily attainable using conventional equipment and techniques. DLM must build upon the opportunities presented by the technology transfer of the GGN project by extending the use of GPS into other fields and investigating other possible uses. The skills of the key personnel assigned to the project must be tapped and their initiative rewarded.

The Land Information Management (LIM) Strategy (July 1991) identified the establishment of a new geodetic network as a major need in the development of Guam's Land Information Systems (LIS). The 1993 GGN provides an unambiguous precise coordinate system as the basis for Guam's LIS. The strategy provided a number of recommendations for the improvement, management and integration of Guam's land information. It is now appropriate for DLM and GovGuam to re-examine the LIM Strategy to ensure a planned, logical, fully integrated approach to the management and integration of the various data sets.

4.13 Recommendations

The following recommendations are made for DLM's consideration:

1. The adoption of a new datum and map projection necessitates the transformation of the Adjusted Layer in DLM's GIS and the digital orthophoto data. This process may not be a simple matter as transformations are complex procedures.

   It is recommended that DLM staff should acquire a thorough understanding of map projections, geodetic datums and transformations and consider engaging a consultant to supervise the transformation process.

2. Local distortions in the 1963 Tertiary Network are unacceptably large and will create similar distortions if any dependent surveys are transformed to the 1993 geodetic datum using island wide parameters.

   It is recommended that DLM consider developing local grid transformation parameters to enable the transformation of all data to the 1993 geodetic datum.

3. Long term success of the Mark Maintenance Program is dependent upon the appointment of a Mark Maintenance Officer.

   It is recommended that DLM create the position of Mark Maintenance Officer within the Geodetic Section and appoint a suitable person to the position.

4. The distribution of appropriate information about the network and mark maintenance is crucial to the long term success of the Mark Maintenance Program and is very cost effective.

   It is recommended that DLM revise the "Save That Survey Mark" brochure, print another batch of brochures and make them readily available to the utility agencies, contractors and the public.

5. The new Geodetic Section is responsible for ongoing maintenance and extension of the 1993 GGN and the application of GPS techniques, however its creation and the allocation of resources has not been formalised.

It is recommended that DLM formally create the Geodetic Section within Survey Division and that it be allocated the necessary resources in the form of personnel, office space, furniture, equipment, vehicles and ongoing funding to enable it to carry out its functions and maintain and replace equipment as necessary.

6. Public Law 23-31 provides the Territorial Surveyor with the powers to maintain the 1993 GGN, to recover the costs of reinstating or repairing survey marks and impose penalties for disturbing or destroying marks. Unless these powers are used there is a very real danger that utility agencies and contractors will ignore these provisions and the network could go the way of the 1963 GGTN.

It is recommended that the Territorial Surveyor takes the strongest action possible to enforce the provisions of Public Law 23-31 related to protection of marks to demonstrate that DLM is serious about the preservation of the network and publicises his actions in this regard.

7. To ensure that the Mark Maintenance Program maintains its effectiveness it would be appropriate to review the program at the end of the initial inspection cycle.

It is recommended that DLM reviews the Mark Maintenance Program at the end of the initial inspection of marks.

8. To take full advantage of the 1993 GGN, all survey practices and procedures should be reviewed and modernised with the introduction of appropriate techniques and standards. It is suggested that such expertise should be sought off-island to ensure the injection of new ideas.

It is recommended that DLM engage the assistance of a suitably qualified consultant, in modern survey techniques and practices, to coordinate the total revision of Guam's Survey Law, Survey Regulations and the Survey Manual.

9. The 1993 GGN has been established as a result of the serious problems with the cadastre and in particular the large gaps and overlaps that exist in some areas. The completion of this project provides the opportunity to start resolving some of these boundary problems especially in areas where redevelopment is being considered but is being hampered by the uncertainty of the extent of ownership.

It is recommended that DLM engage the assistance of a suitably qualified consultant, to coordinate a Pilot Study within a Confused Boundary Area from which the appropriate survey and legal procedures will be developed for the resolution of all such boundary problems throughout Guam.

10. DLM does not charge surveyors for the examination of survey maps before acceptance by the Territorial Surveyor. The levy of reasonable fees would cover the costs of examination and could be used to fund cadastral improvement activities such as check surveys, surveys in Confused Boundary Areas and other initiatives.

It is recommended that DLM introduce fees for the examination of survey maps.

11. The Government of Guam has a substantial investment in the cadastral system. Citizens and developers must have trust in the cadastral system to invest with confidence and this confidence will only result from security of tenure and

boundaries. It is therefore essential that Survey Division is staffed with appropriately qualified and experienced people and that it is allocated the resources to maintain and improve Guam's cadastre.

It is recommended that DLM review the structure, role and resources of Survey Division to ensure that it is adequately equipped to carry out its existing tasks, meet the obligations placed upon it by the 1993 GGN and to gradually improve Guam's cadastre to meet the community's expectations and demands.

12. There was substantial geophysical activity in 1993, there has been a loss of bench marks from the 1963 levelling network. The limited number of recovered levelled marks provide poor coverage of the island and a comparison between the OSU91A and GPS/levelling derived geoid values indicate possible degradation of the levelling. A precise levelling network and reliable vertical datum are necessary for large scale engineering and development projects.

It is recommended that DLM give serious consideration to relevelling the vertical network to determine the extent of degradation due to geophysical activity and to define a new vertical datum for Guam.

13. Geodetic surveying is a complex science requiring the appropriate educational background. DLM does not have any personnel with this level of expertise. Mr Torres and Mr Ragadio have acquired a comprehensive knowledge of the GPS techniques necessary to maintain and extend the 1993 GGN, however they lack the educational background.

It is recommended that DLM give consideration to extending the training of these two key personnel to full bachelors degree level.

14. There is a recognised lack of well qualified registered surveyors with an up-to-date knowledge of modern survey techniques and procedures within DLM.

It is recommended that DLM give consideration to appointing at least one and preferably two professionally qualified surveyors. Ideally they should be drawn from overseas where they have had extensive exposure to a variety of modern techniques so that they can guide DLM and the private sector in the development of modern and appropriate procedures.

15. The project has highlighted the need for Guam's surveying community to undertake professional development and introduce modern survey techniques and practices. One way of fostering such development would be a greater involvement with professional surveyors throughout the Western Pacific, South East Asia and Australia.

It is recommended that DLM actively encourage the involvement of Guam's surveying community with fellow professionals throughout the region.

16. Both DLM and the private surveyors recognise the limited survey education opportunities on Guam. Because of the relatively low demand it would seem unlikely that a full bachelors degree course will ever be introduced. It is possible that some cooperative relationship could be established between the University of Guam and an off-island university. Such a relationship with a university with a good reputation for

its survey education could enable a very much needed improvement in the education of Guam's surveyors.

It is recommended that DLM and the surveying profession consider the possibilities of promoting a cooperative relationship between the University of Guam and a suitable off-island university to improve the survey education available on Guam for both those interested in entering the surveying profession and those wishing to extend their existing surveying education.

17 The Land Information Management (LIM) Strategy (July 1991) provided a number of recommendations for the improvement, management and integration of Guam's land information. It is now appropriate for DLM and GovGuam to re-examine the LIM Strategy.

It is recommended that DLM and GovGuam re-examine the LIM Strategy to ensure a planned, logical, fully integrated approach to the management and integration of the various land related data sets.

The South Australian Department of Environment and Natural Resources has the necessary expertise to provide assistance in relation to a number of the above recommendations and would welcome the opportunity to further discuss these recommendations with DLM.

5.1 Conclusion

This project has provided a modern, accurate and readily accessible geodetic network to support Guam's surveying, land administration and land information needs into the next century. It will become the basic spatial framework that will enable integration of a wide variety of land related information.

Utilisation of the network will ensure that surveys are properly controlled and will prevent the proliferation of gaps and overlaps in cadastral surveys. It does not however provide an instant answer to Guam's existing problems of gaps and overlaps in the cadastre that have arisen over a number of years due to unsound survey practices. Surveyors must still take into account all available evidence when defining boundaries and use the network initially as control not as boundary evidence. By proper connection of surveys to the network, the 1993 GGN will eventually become a system not only of accurate control points but also of well maintained reference marks. They will become the primary evidence of boundaries and enable boundary retracement from the network. In areas where all boundaries have been adequately connected to the network there will be the opportunity for the creation of a coordinated cadastre.

To ensure that Guam gains the maximum benefit from the project there must be an ongoing commitment from GovGuam and DLM in particular to pursue the goals of the project. It is imperative that they provide the necessary support for ongoing maintenance and extension of the network into all new areas of development. If this commitment cannot be made then there is a very real danger that the cost of establishing the 1993 GGN could be wasted.

There must also be a commitment to proper utilisation of the network and a general improvement and overhaul of survey practices in Guam. Only in this way will the full benefits and opportunities available from such a precise homogeneous satellite based geodetic network be realised. The security of tenure and boundaries reliant on an unambiguous cadastre will result in an improved land administration system. The benefits will flow through to all areas of society as only with security of tenure and boundaries and a sound land administration system will citizens and developers invest in appropriate development.

Serious consideration of the recommendations is urged.

5.2 Acknowledgments

Successful implementation of the project can be credited to a number of factors. Although there was a constant struggle to maintain the schedule the project was well conceived and designed.

The efforts of the former Director, DLM, Mr Frank Castro, in pursuing and ensuring implementation should be acknowledged, without his determination the project would not have commenced. He gave the project his full support during his tenure and his successor, Mr Tony Martinez, continued the support. The contribution of the DLM project team in carrying out the survey activities was essential, they were very ably guided by the Guam

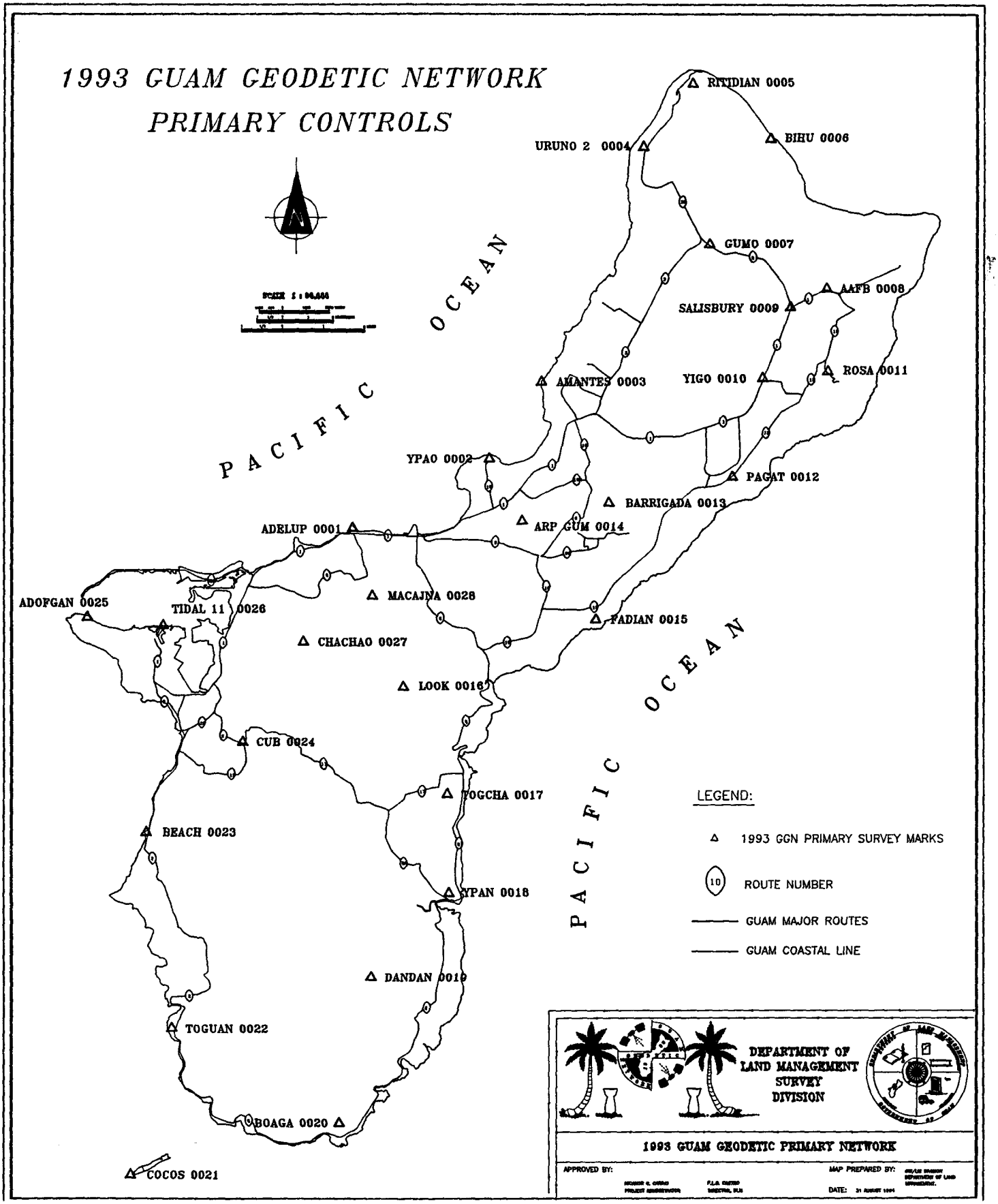
Team Leader, Mr Torres, who not only created a unified team and inspired them to give their best but also acquired considerable expertise in GPS surveying during the project.

The support of the Territorial Planning Council, and in particular of Mr Marcel Camacho, former Executive Officer, and his staff was invaluable and greatly appreciated. He played an important role in assisting Mr Castro to get the project underway and offered support throughout the project

The contribution of all the DENR consultants must be acknowledged. The short term consultants, Mr Andrew Jones (Geodesist), Mr Chris Jordan (Mark Maintenance Expert), Mr Peter Kentish (Survey Legislation Expert) and Mr Craig Macauley (Survey Data Base Expert) made an important contribution providing the necessary supporting infrastructure to ensure sustainability. Their contribution was not limited to their short time on-island and completion of their formal tasks as they continued to provide support and valuable input throughout the project. The support of the Project Director, Mr Tony Bew, was essential to successful completion of the project. The assistance of Mr Graham Baggs and Mr Dave Burgess of DENR's Resource Information Group in plotting information to assist in definition of the vertical datum and the interpolation of geoid-spheroid separation values was invaluable. Finally recognition and appreciation of the contribution made by Mr David Borchardt (Tertiary Network Expert) must be recorded. Among other things he was responsible for day to day management of the field activities, data processing and training. His untiring efforts ensured the successful completion of the project on schedule.

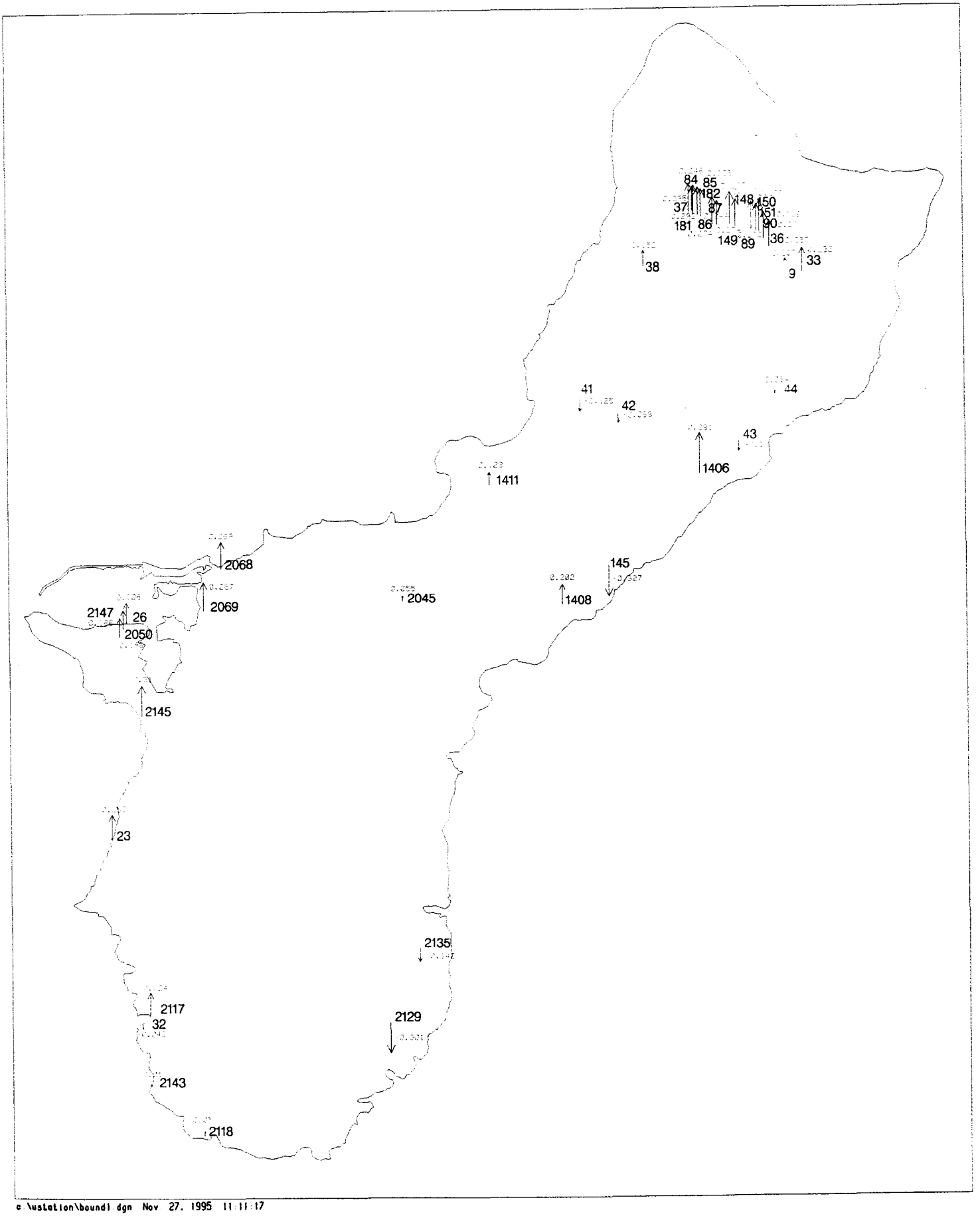
APPENDIX 1

Primary Network Diagram


1993 GUAM GEODETIC NETWORK
PRIMARY CONTROLS
RITIDIAN 0005
BIHU 0006
URUNO 2 0004
GUMO 0007
AAFB 0008
SALISBURY 0009
ROSA 0011
YIGO 0010
AMANTES 0003
PACIFIC OCEAN
YPAO 0002
PAGAT 0012
BARRIGADA 0013
ARP GUM 0014
ADELUP 0001
MACAJNA 0028
ADOFGAN 0025
TIDAL 11 0026
FADIAN 0015
CHACHAO 0027
LOOK 0016
CUB 0024
TOGCHA 0017
BEACH 0023
YPAN 0018
DANDAN 0019
TOGUAN 0022
BOAGA 0020
COCOS 0021
LEGEND:
1993 GGN PRIMARY SURVEY MARKS
ROUTE NUMBER
GUAM MAJOR ROUTES
GUAM COASTAL LINE
DEPARTMENT OF LAND MANAGEMENT SURVEY DIVISION
1993 GUAM GEODETIC PRIMARY NETWORK
APPROVED BY:
MAP PREPARED BY:
DATE:

APPENDIX 2

OSU91A - GPS/Levelling Geoid/Spheroid Separation Differences



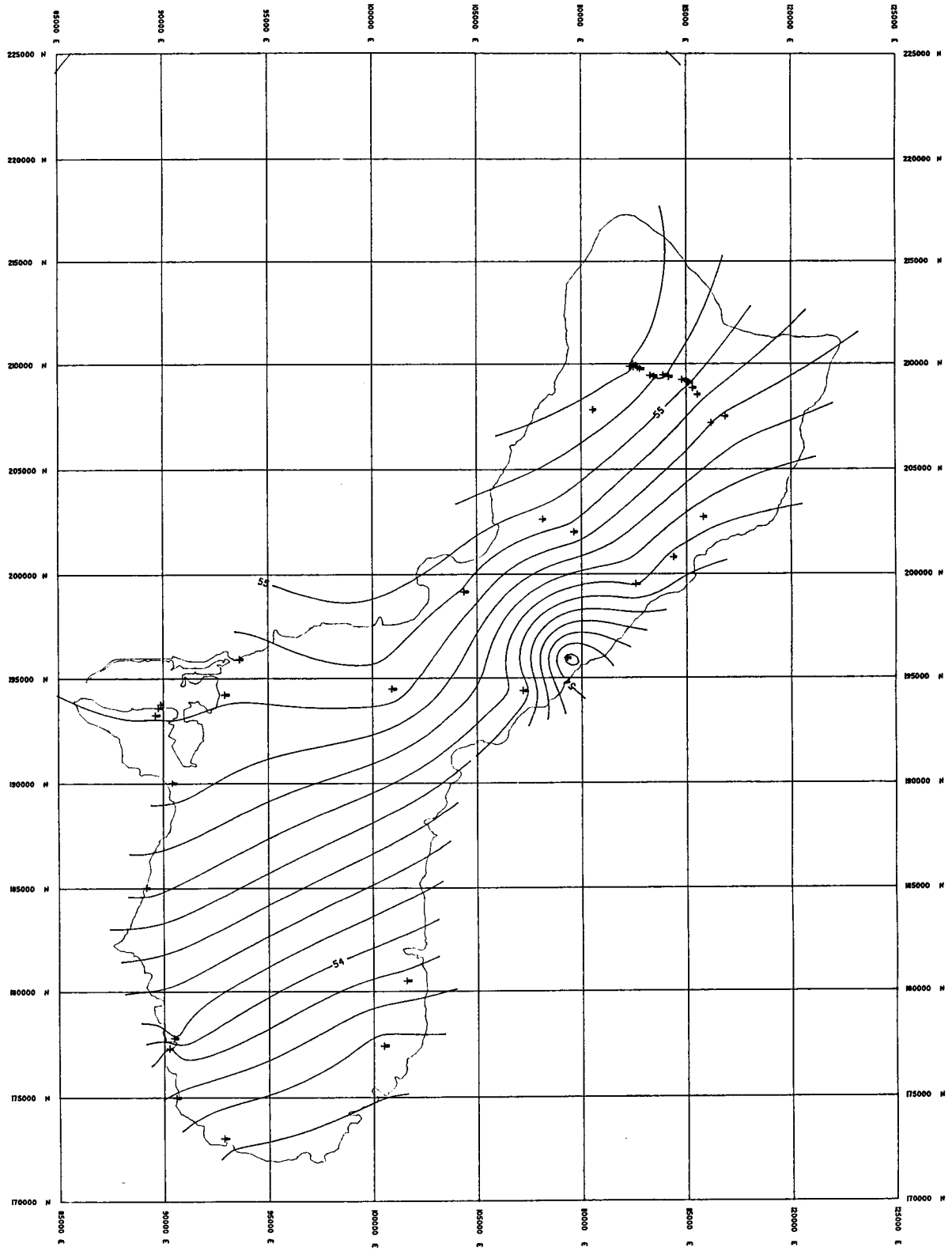
c:\ustation\boundl.dgn Nov 27, 1995 11:11:17

APPENDIX 3

Geoid/Spheroid Separation Map

Initial Plot

1993 GUAM GEODETIC NETWORK



GEOID MAP
(GPS - LEVELING)
GRS 80 SPHEROID

Coordinates - Guam Map Grid
Datum - NAD83
Contour Interval - 0.10m

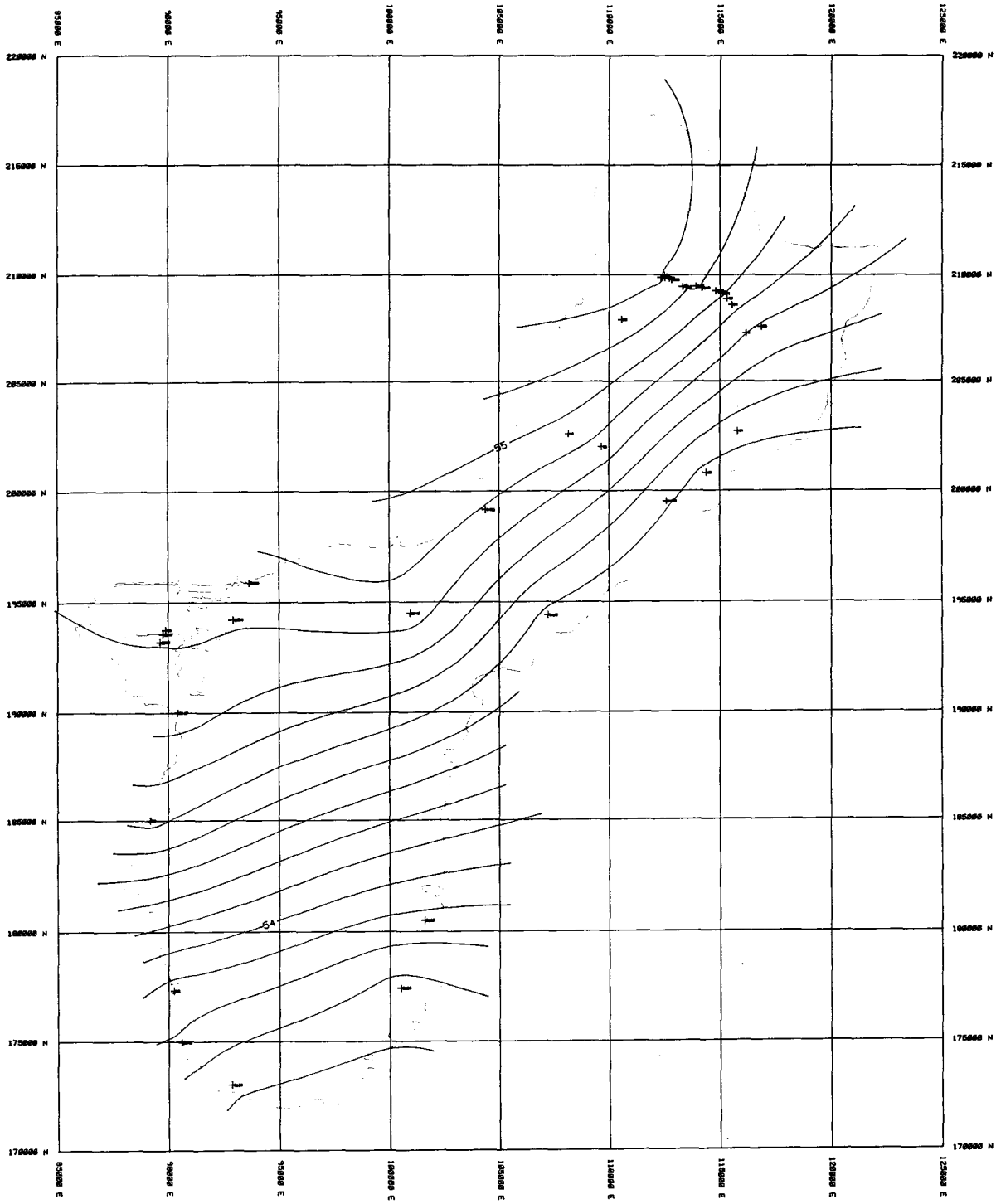
Prepared by : SA DENR

APPENDIX 4

Geoid/Spheroid Separation Map

Final Plot

1993 GUAM GEODETIC NETWORK



GEOID MAP
(GPS - LEVELING)
GRS 80 SPHEROID

Coordinates - Guam Map Grid
Datum - NAD83
Contour Interval - 0.10m

Prepared by : SA DENR

APPENDIX 5

GPS Equipment Warranty & Maintenance Agreement